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Acquisition, Design Modification, Assembly, and Ground Test of NPS
Hummingbird Remotely Piloted Helicopter

by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1993

Daniel J. Collins, Chairman,
Department of Aeronautics and Astronautics

Unclassified

Security Classification of this page

REPORTS DOCUMENTATION PAGE

1a Report Security Classification UNCLASSIFIED		1b Restrictive Markings	
2a Security Classification Authority		3 Distribution Availability of Report Approved for public release; distribution isunlimited.	
2b Declassification/Downgrading Schedule		5 Monitoring Organization Report Number(s)	
6a Name of Performing Organization Naval Postgraduate School	6b Office Symbol *(If Applicable)* 31	7a Name of Monitoring Organization Naval Postgraduate School	
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000		7b Address *(city, state, and ZIP code)* Monterey, CA 93950-5000	
8a Name of Funding/ Sponsoring Organization	8b Office Symbol *(If Applicable)*	9 Procurement Instrument Identification Number	
8c Address *(city, state, and ZIP code)*		10 Source of Funding Numbers	
Program Element Number	Project No.	Task	Work Unit Accession No.

11 Title (Include Security Classification)
Acquisition, Design Modification, Assembly, and Ground Test of NPS Hummingbird Remotely Piloted Helicopter

12 Personal Author(s)
Fick, Gregory J.

13a Type of Report Master's Thesis	13b Time Covered From To	14 Date of Report (year, month, day) 1993 September 23	15 Page count 93

16 Supplementary Notation
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes:	Field	Group	Subgroup

18 Subject Terms *(continue on reverse if necessary and identity by block number)*
RPH, DESIGN MODIFICATION, ASSEMBLY, GROUND TEST

19 Abstract *(continue on reverse if necessary and identity by block number)*

The *Hummingbird* is a 150-lb. gross weight, remotely piloted helicopter (RPH) with a 50-lb. payload and a rotor radius of 10.25 ft. It is powered by a 25 h.p. air cooled two-cylinder Westlake engine. As such it represents one of the largest RPH's in the world. It was purchased from Gorham Model Products in 1992 to provide a suitable rotor craft research flight test platform for the Department of Aeronautics and Astronautics at the Naval Postgraduate School. The helicopter was delivered disassembled and was accompanied by an ample supply of replacement and spare parts. Also included was a second helicopter in a partially assembled condition that had been previously flown. Assemblies provided comprised the chassis, main rotor transmission, rotor head assembly and tailboom with tail rotor gear box and rotor. The task undertaken by this thesis was to fabricate one complete fully operable RPH and to design, fabricate and install whatever new assemblies that were required for its NPS mission and to make up for deficiencies in the previous design. The work completed required: (1) Design, fabrication and installation of a new skid-type landing gear system; (2) Redesign, and incorporation of a new engine mount system; (3) Modification of the engine and main rotor transmission coupling; (4) Upgrade of the electrical system and elongation of the nose section; and (5) Conduct initial engine run. Recommendations for future modifications to the helicopter and laboratory facilities, and development of a static hover test fixture are also included.

20 Distribution/Availability of Abstract ▪ unclassified/unlimited ▪ same as report ▪ DTIC users		21 Abstract Security Classification Unclassified	
22a Name of Responsible Individual E. Roberts Wood		22b Telephone *(Include Area Code)* (408) 656-2897	22c Office Symbol AAWD

DD FROM 1473, 84 MAR 83 APR edition may be used until exhausted security classification of this page

All other editions are obsolete Unclassified

ABSTRACT

The *Hummingbird* is a 150-lb. gross weight, remotely piloted helicopter (RPH) with a 50-lb. payload and a rotor radius of 10.25 ft. It is powered by a 25 h.p. air cooled two-cylinder Westlake engine. As such it represents one of the largest RPH's in the world. It was purchased from Gorham Model Products in 1992 to provide a suitable rotor craft research flight test platform for the Department of Aeronautics and Astronautics at the Naval Postgraduate School. The helicopter was delivered disassembled and was accompanied by an ample supply of replacement and spare parts. Also included was a second helicopter in a partially assembled condition that had been previously flown. Assemblies provided comprised the chassis, main rotor transmission, rotor head assembly and tailboom with tail rotor gear box and rotor. The task undertaken by this thesis was to fabricate one complete fully operable RPH and to design, fabricate and install whatever new assemblies that were required for its NPS mission and to make up for deficiencies in the previous design. The work completed required: (1) Design, fabrication and installation of a new skid-type landing gear system; (2) Redesign, and incorporation of a new engine mount system; (3) Modification of the engine and main rotor transmission coupling; (4) Upgrade of the electrical system and elongation of the nose section; and (5) Initial engine testing. Recommendations for future modifications to the helicopter and laboratory facilities, and development of a static hover test fixture are also included.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

I wish to acknowledge several key people, without whom completion of this project could never have been possible. First, my deepest appreciation goes to Aerospace Engineering Technician Don Meeks, who provided invaluable assistance throughout all phases of this project and dedicated vast amounts of time towards ensuring its completion. Department of Aeronautics and Astronautics Laboratory Manager Pat Hickey also deserves my profound appreciation for providing vital sanity checks, and improvements when necessary, to all the major design modifications and for ensuring the timely fabrication of needed parts and assemblies. Also deserving my gratitude for the expedicious and quality manufacture of assemblies required for the modifications is Model Maker Don Harvey. For dedicating two days of his personal time during the rigging of the main and tail rotor control linkages and allowing me to draw on his vast knowledge of.remotely piloted helicopters, a special thank you goes to Mr. Dennis King. Finally, for his support throughout the actual writing of this document, my appreciation goes to Professor Rick Howard.

I. INTRODUCTION

In an effort to expand its capabilities in the area of helicopter research, the Department of Aeronautics and Astronautics at the Naval Postgraduate School purchased in 1992 the *Hummingbird* remotely piloted helicopter (RPH) from Gorham Model Products Inc. The RPH was delivered disassembled and was accompanied by a second, previously flown, partially disassembled helicopter. Along with the two vehicles a supply of replacement and spare parts adequate for the complete fabrication of two *Hummingbird* class helicopters was provided. The task undertaken by this thesis was to fabricate one complete fully operable RPH and to design, fabricate and install whatever new assemblies that were required for its NPS mission and to make up for deficiencies in the previous design. Final assembly was followed by a ground test of both the engine and the helicopter.

In an effort to prolong the service life and increase the survivability of the Hummingbird beyond that of the original design three major design modifications were introduced to the landing gear assembly, the main transmission and engine coupling and the engine mounting system. Minor modifications were also incorporated into the nose section, the electrically powered flight control system, and the rotor head assemby.

In order to facilitate the fabrication of a second RPH and also provide a source document for the periodic maintenance of *Hummingbird* I; an itemized inventory of parts acquired from Gorham Model Products [Ref. 2] and a comprehensive list of hardware, service and supply companies utilized during the assembly of the helicopter were provided as Appendix A. A detailed procedure for the removal and installation of the engine, and portions of the Westlake engine operators manual [Ref. 3] pertinent to the performance of maintenance on the engine were provided as Appendices B and C respectively.

During the redesign, assembly, and test of the helicopter and based on previous and current reasearch associated with the RPH, recommendations for seven future modifications to the flight vehicle are given. Considering the current and expected future expansion of helicopter research at NPS and its possible selection by the U. S. Army as one of three national Centers of Excellence in rotorcraft research, three recommendations for developement of recently acquired spaces in Building 230 into a dedicated, fully tooled RPH laboratory with nearby outdoor test area also surfaced.

With complete assembly, design modification and ground tests of *Hummingbird* I accomplished, the Department of Aeronautics and Astronautics at the Naval Postgraduate School has been provided a fully operational flight vehicle and base platform for future scale model helicopter research in areas such as NOTAR and Higher Harmonic Control (HHC).

II. BACKGROUND

A. PREVIOUS RESEARCH

Expanding research in areas such as Higher Harmonic Control (HHC) and No Tail Rotor (NOTAR) generated the requirement within the Department of Aeronautics and Astronautics at the Naval Postgraduate School for the acquisition or fabrication of a remotely piloted helicopter (RPH) of suitable size to be used as a flight test platform for these projects. Requirements for the new RPH included: matching full scale rotor blade Reynolds numbers; being of a size compatible with the NASA Langley 1/4 scale wind tunnel; capable of operating at a derated power setting to prolong aircraft service life; having ample spare parts for repair and maintenance; having a payload capacity more than 15 pounds; and having a design suitable for incorporating HHC and NOTAR modifications. Based on these requirements, LT. James L. Vandiver conducted as his thesis project a detailed design analysis to quantify these needs and acquire a suitable platform.

The research conducted by LT. Vandiver included trend analyses of existing full scale helicopters, tradeoff studies, and a constraint analysis of the main rotor system. Examples of these have been included as Figures 1 through 3 respectively. [Ref. 1] These analyses produced initial design parameters such as; a 130 pound gross weight, a 87.5 pound empty weight, a rotor radius of 4.86 feet, and a disk loading of 1.75 pounds per square foot. Using this data, the choice of whether to design and fabricate or to acquire through the commercial market an adequate RPH was made. "The second alternative, being the most productive and time smart, was chosen." [Ref. 1] With this decision made, he then embarked on a prolonged search throughout the commercial market, eventually locating and purchasing a helicopter that satisfied NPS requirements.

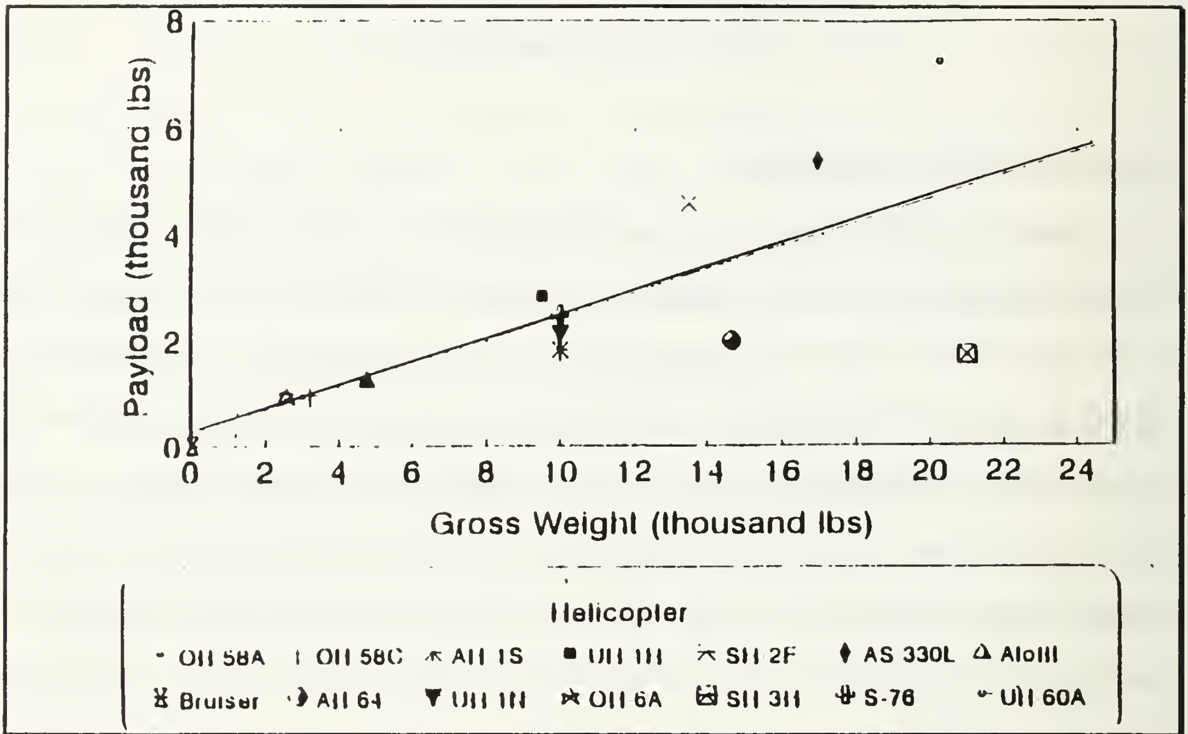


Figure 1. Payload vs Gross Weight Trend Analysis [Ref. 1]

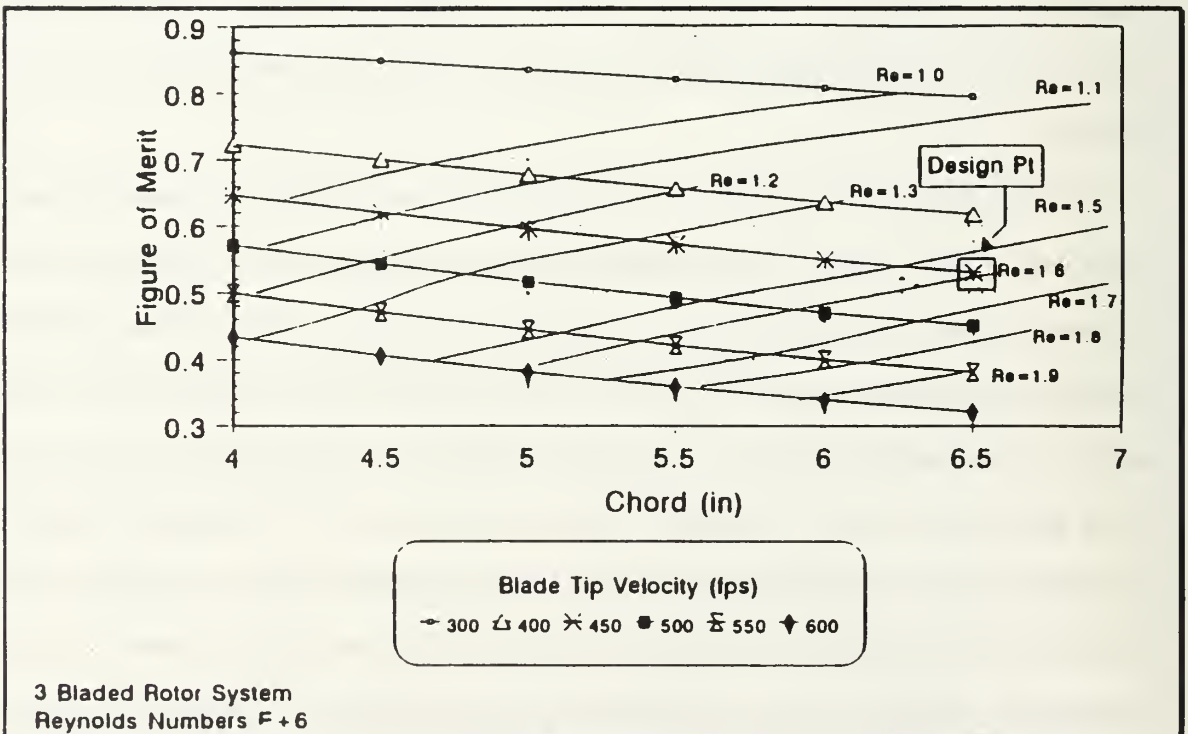


Figure 2. Figure of Merit and Reynolds Number Tradeoff [Ref. 1]

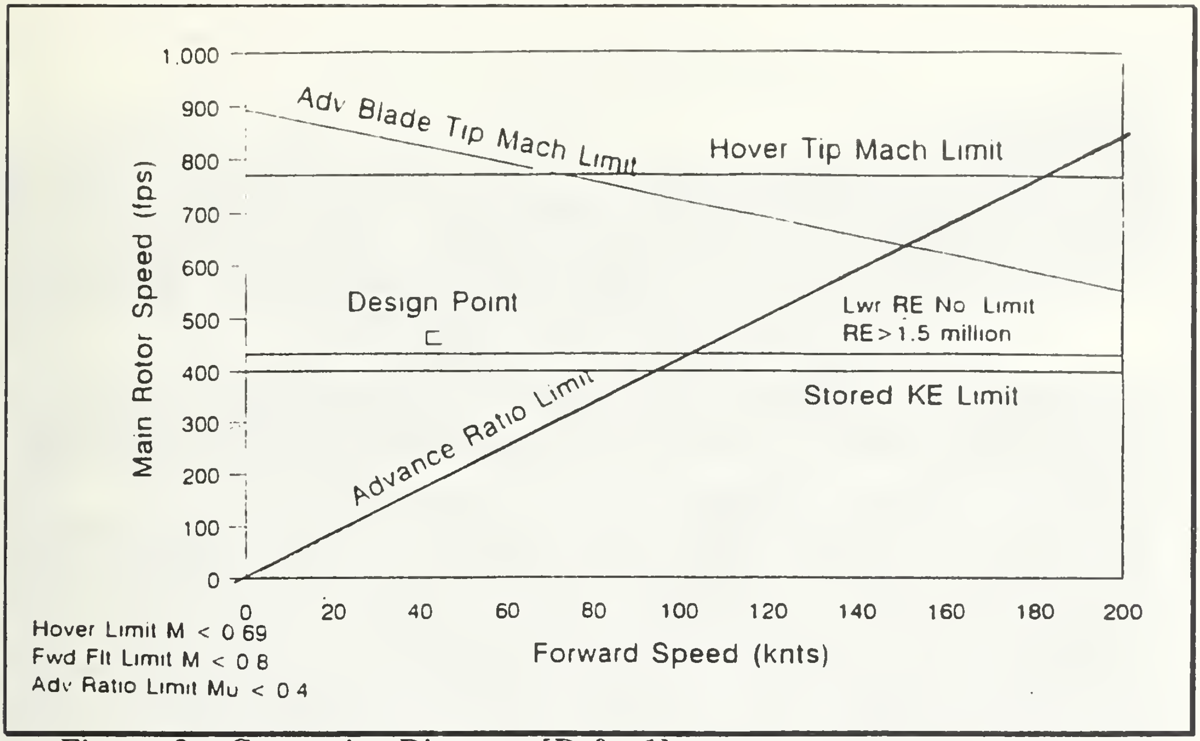


Figure 3. Constraint Diagram [Ref. 1]

B. GORHAM MODEL PRODUCTS

The helicopter that was purchased by NPS was designed and produced by Mr. John Gorham, owner of Gorham Model Products. Under contract with MICOM, the U. S. Army's Missile Command, GMP designed and produced ten 165-pound remotely piloted helicopters. They were originally designed as 1/5 scale Hind-D helicopters with the purpose of acting as recognition drones for MICOM 1/5 scale war games. Upon completion of the contract, GMP offered for sale on the commercial market its remaining helicopters. Since the Naval Postgraduate School purchased the last available Hind-D, it was also given an abundant supply of spare and replacement parts along with a second, partially disassembled, previously flown and crashed helicopter. Figure 4 shows one of these RPHs in hovering flight. Figure 5 shows Mr. Gorham surrounded by six of his Hind-D helicopters. Table 1 contains data on the Gorham 1/5 scale Hind-D RPH renamed *Hummingbird* 1. [Ref. 1]

Figure 4. Hovering Gorham 1/5 Scale RPH [Ref. 2]

Figure 5. Mr. Gorham with his Hind-D RPHs [Ref. 2]

TABLE 1: GORHAM HIND RPH DATA

Hummingbird:		
Characteristics		
Weights		
Max Gross Weight	165 lbs	
Empty Weight	115 lbs	
Fuel capacity	6.5 lbs	
Rotor Parameters	**Main**	**Tail**
Radius (R)	5' 3"	12.5"
Chord (c)	6"	2.625"
Solidity (sigma)	0.0061	0.02
No. of blades (b)	2	3
Tip speed	303 fps	241 fps
Twist	-5	0
Hinge offset ration (e/R)	0.127	0.24
Airfoil	NACA 0012	NACA 0012
Engines		
Type	Westlake 342 Series 2100D	
Number	1	
Maximum Usable Power	25 BHP @ 7000 rpm	
Maximum Torque	25 ftlb @ 4000 rpm	

C. THE CHRONOLOGY OF MODIFICATION AND ASSEMBLY

From initial parts inventory through the final stages of ground tests, a specific sequence of events was followed to ensure all modifications and additions to the original design were incorporated into *Hummingbird* 1. An inventory and organization of all new and used parts and assemblies acquired from GMP was completed at the onset of the project. Figures 6 and 7 depict the major assemblies that were acquired. The engine compartment and main transmission of the RPH that had flown previously were then disassembled to analyze design deficiencies in the area of the main transmission and engine

output shaft coupling. Figure 8 depicts the previously flown chassis. Through this disassembly, a procedure for the assembly of the engine compartment of the new RPH was established. Following this, all new parts and assemblies that were found to be necessary during the disassembly were designed and manufactured. The drive train, landing gear system, and electronic system were then installed. Next, the fiberglass forward fuselage and tailboom were secured to the chassis, aligned and fitted together. Pinholes in both the fiberglass sections were then filled and both sections were primed and painted. The main and tail rotor systems were assembled and rigged for flight using rigging data included in Appendix D. Finally, the helicopter was weighed, balanced, and statically ground tested.

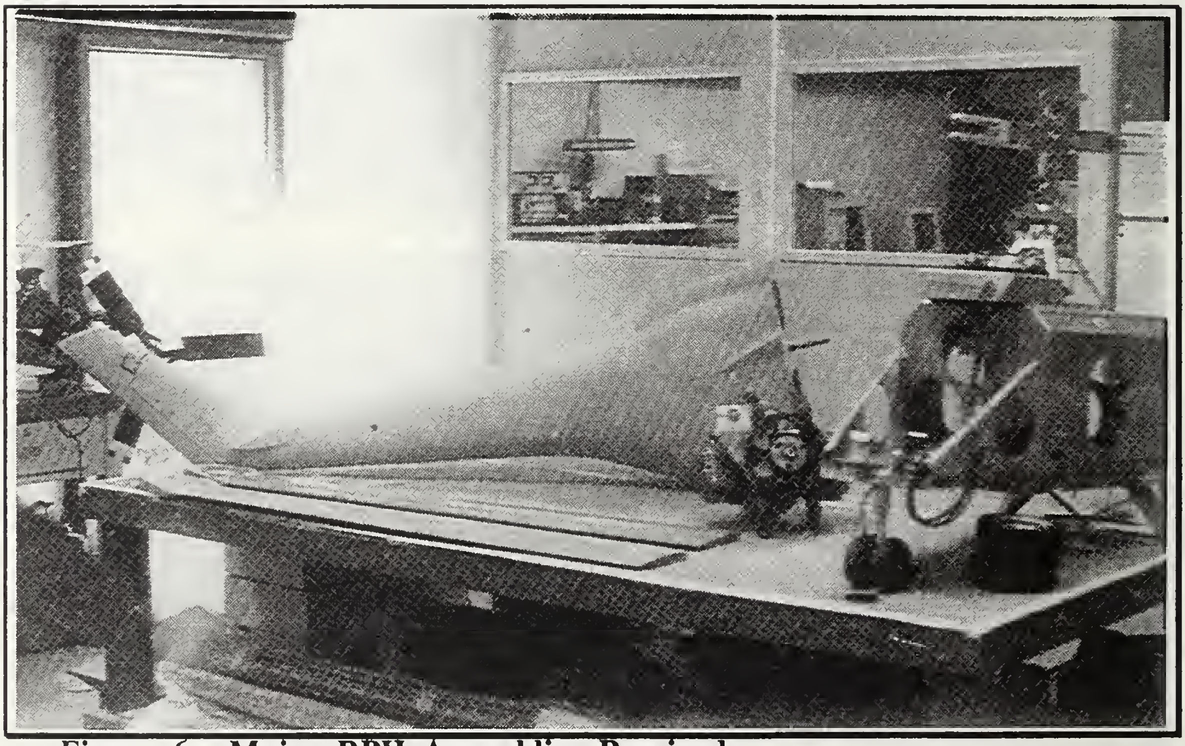


Figure 6. Major RPH Assemblies Received

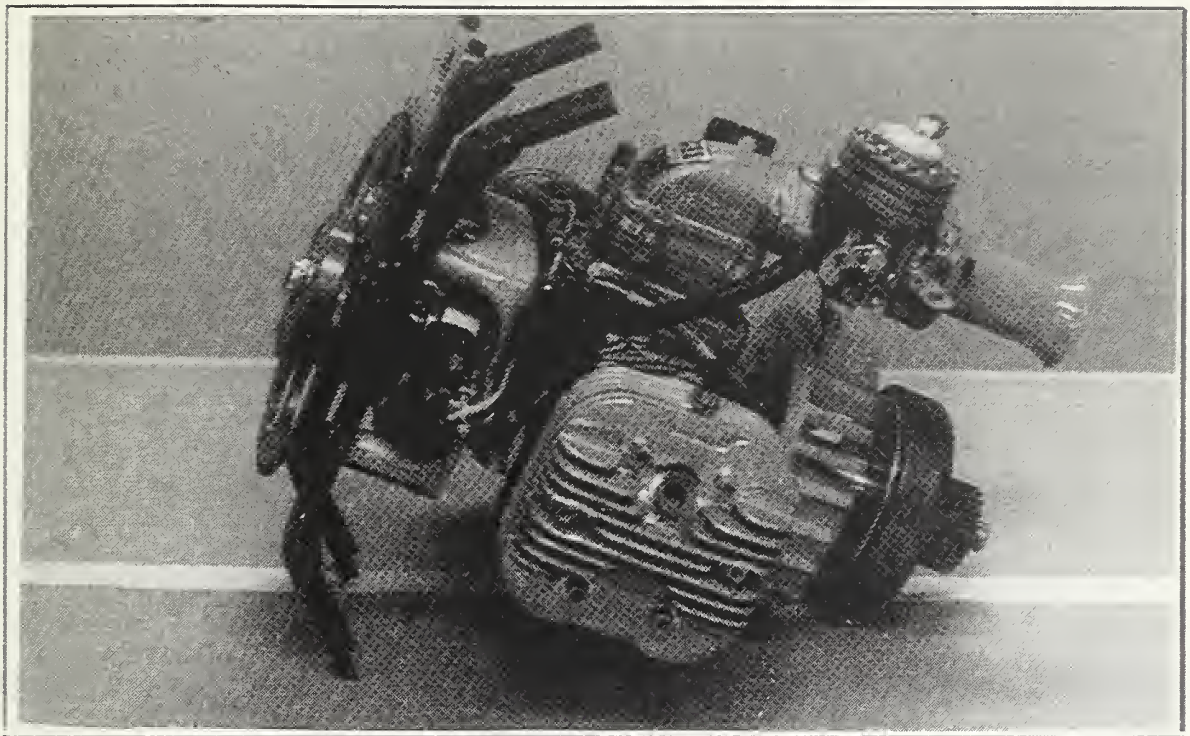


Figure 7. Westlake 25 BHP Engine

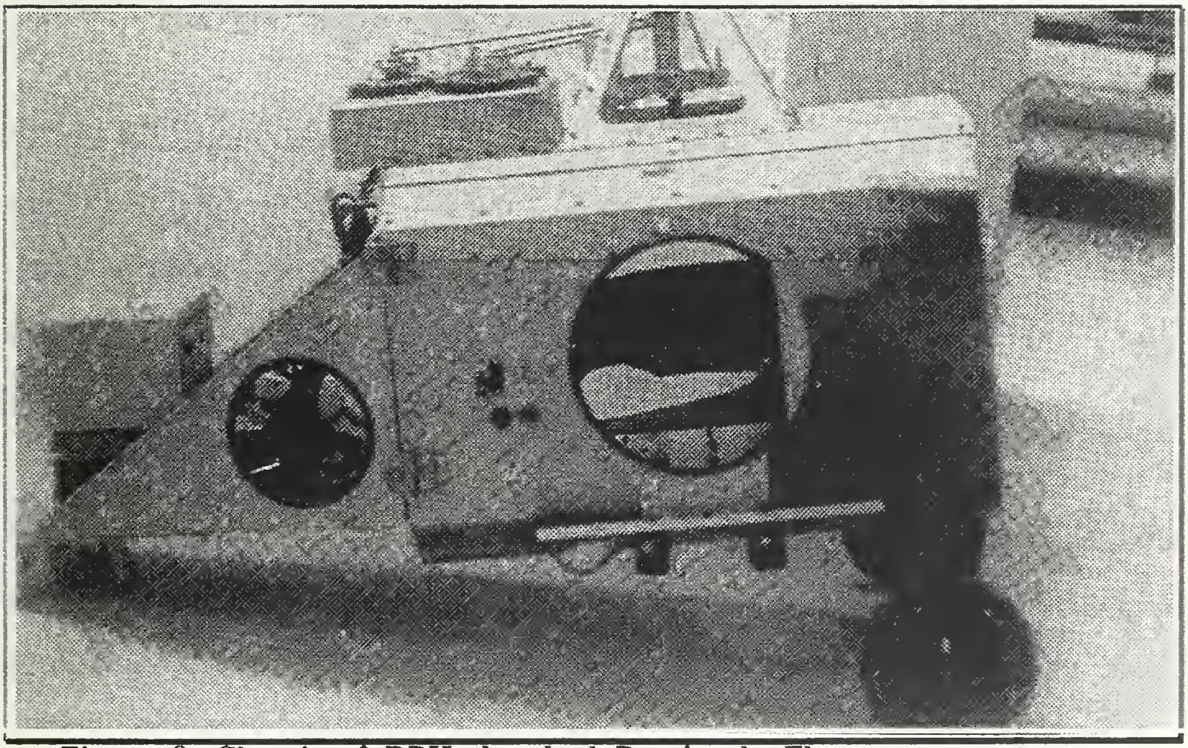


Figure 8. Chassis of RPH that had Previously Flown

III. DEFICIENCIES FOUND

A. DEFICIENCIES FOUND IN THE RPH ORIGINAL DESIGN

Careful inspection of the Hind-D RPH that had previously flown revealed requirements for the redesign or modification of four major assemblies. These assemblies included the landing gear system, the engine and its mount system, the nose or electronics compartment and portions of the main rotor assembly.

1. The Landing Gear

The original design of the landing gear assembly, depicted in Figure 9, contained two significant flaws. This rigid tripod type system lacked any load absorbing capability and would collapse in the event of a hard landing. Also, the narrow lateral tread width of 21 inches for this original design made the vehicle a tipover threat during takeoff and landing.

2. The Engine and Mount System

Careful analysis of the main transmission and engine shaft coupling of the RPH that had previously flown showed excessive scorching of the lower end of the main transmission shaft, destruction of the bearings surrounding the shaft, and deterioration of the brass bushing used between the two shafts as seen in Figure 10. The reason for this excessive wear was found in the method by which the engine was originally mounted to the airframe. The two channels mounted to the bottom of the engine as seen in Figure 7, Chapter II, were bolted to the helicopter chassis using rubber washers as spacers. The only other point of attachment for the engine was where its output shaft slid inside the shafting of the main transmission. Therefore, the engine was soft mounted and its output shaft was free to migrate within the main transmission shafting rotating at ten times the

speed as the transmission shafting. Figure 11 shows the engine and transmission coupling where the damage was found.

3. The Nose Section

The nose section or electronics compartment was determined to be of insufficient area to provide the space necessary for the electronics, fuel tank, and ballast weights. The RPH that had flown had ballast weights attached to various places on the nose compartment and the fiberglass forward fuselage to counter an aft center of gravity.

4. The Main Rotor Head

The main rotor head incorporates a Bell-Hiller stabilizer paddle and weights assembly to increase cyclic control power. The centrifugal forces generated by these weighted paddles threatened to cause the paddles to be thrown from the rotor head due to their only being attached by two set screws per paddle. Also, although the main rotor head assembly and the main rotor blades themselves were provided fittings for lead-lag links, no links were provided.

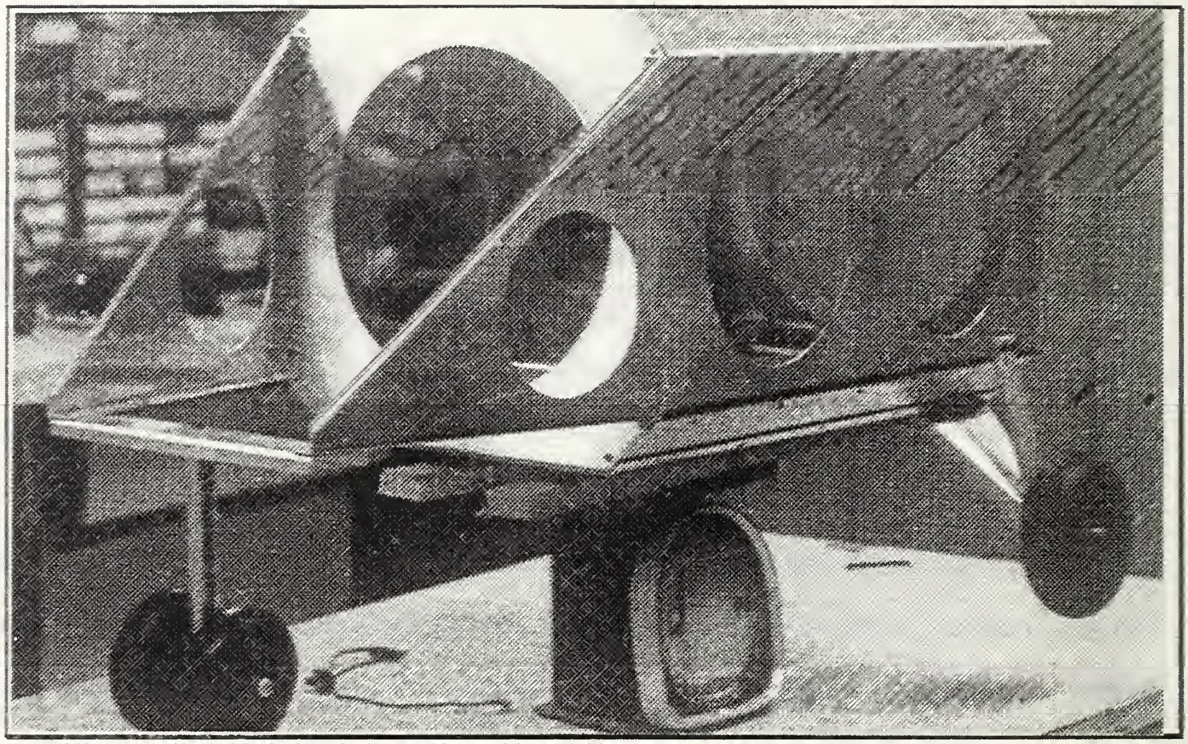


Figure 9. Original Landing Gear System

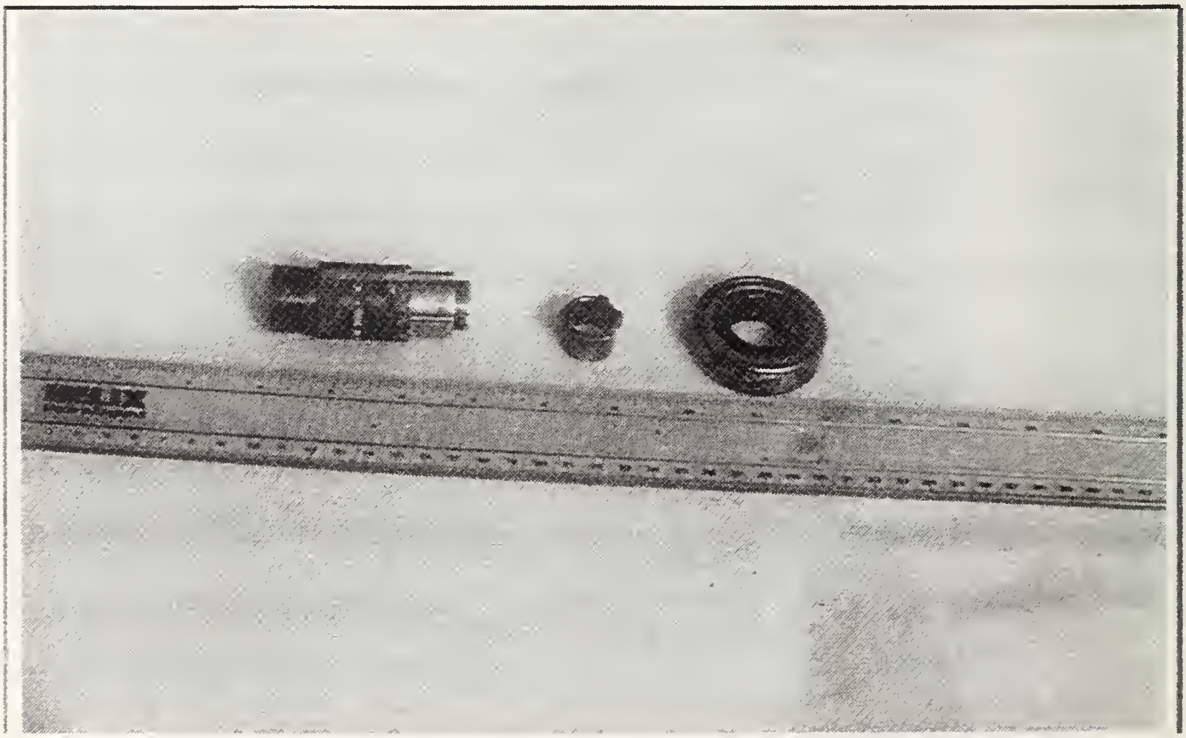


Figure 10. Damaged Bearing and Brass Bushing, and Scorched Shaft

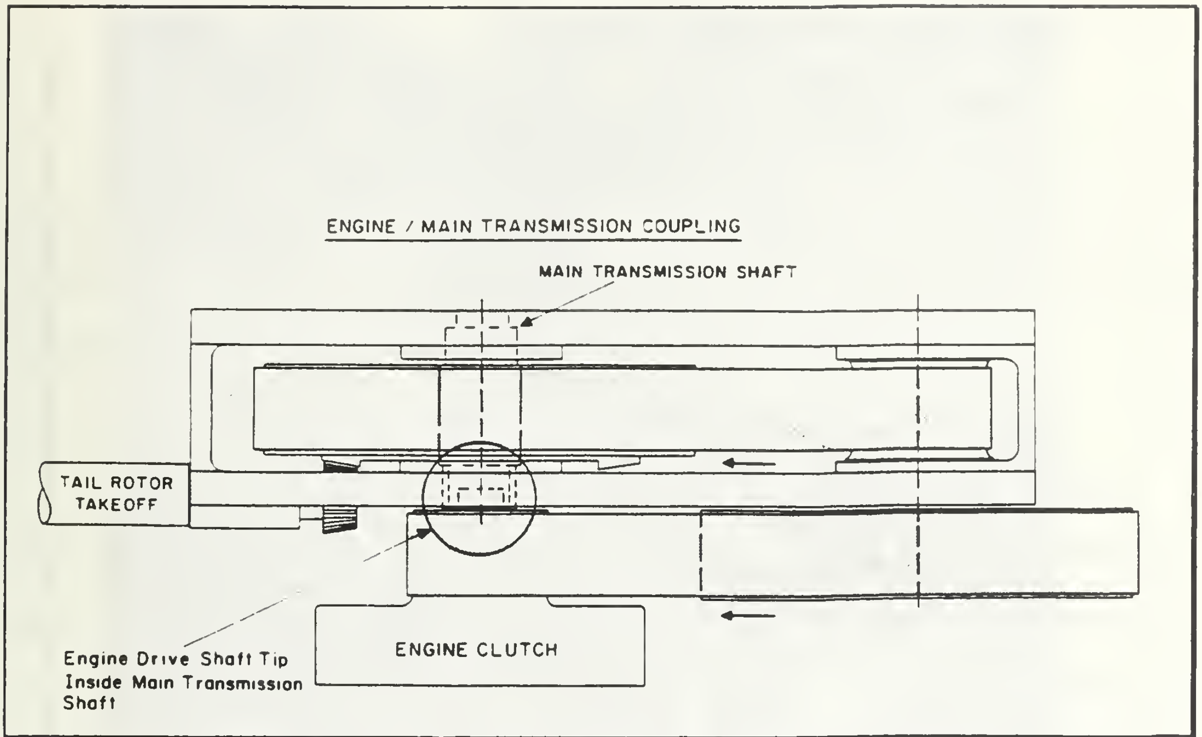


Figure 11. Schematic of Engine and Transmission Coupling

B. MAINTENANCE STAND

During the disassembly of the RPH that had flown, it was found necessary to develop a stand on which the chassis could be placed in an inverted position to facilitate maintenance. The stand that was found proved useful both as a maintenance stand and a test stand for the static ground tests. The maintenance stand is depicted in Figure 12.

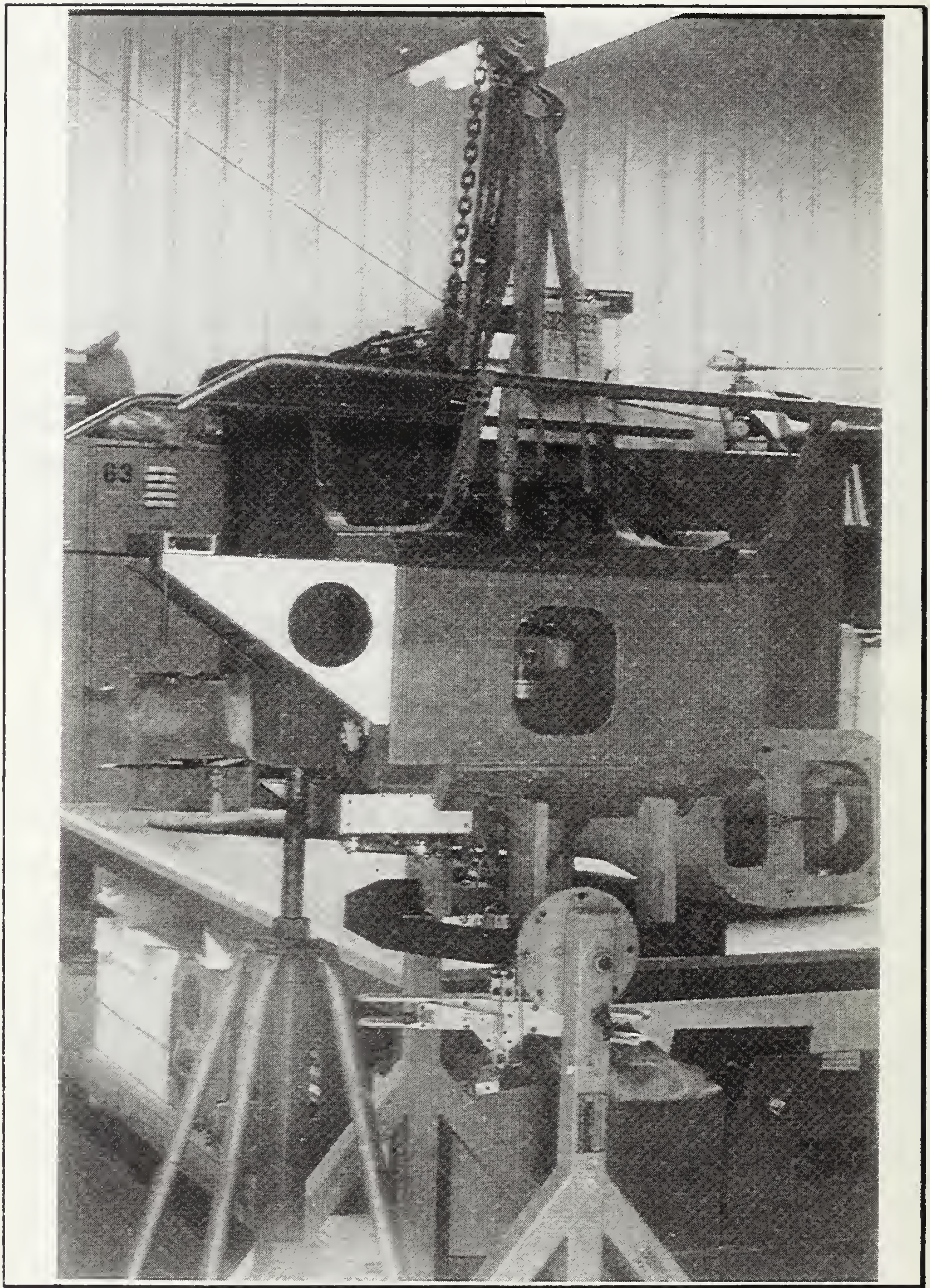


Figure 12. Maintenance Stand

IV. DESIGN MODIFICATIONS

Parts and assemblies were designed and fabricated to correct defects discovered in four seperate areas of the helicopter. These areas included the landing gear system, the engine mounting system with coupling between engine and transmission, the nose section and associated electronics, and portions of the main rotor head assembly.

A. THE LANDING GEAR SYSTEM

A skid type landing gear system was selected to best correct the deficiencies of the original tripod system. As a result of *Hummingbird* 1 having a two bladed main rotor, an undamped skid-type system could be incorporated without concern for ground resonance. Using dimensions obtained from the Robinson R22 and R44 helicopters [Refs. 4 and 5], a tread width to helicopter height ratio was determined and used to initially size the RPH skid system. This system was composed of two skid supports made of 0.375 inch by 1 .0 inch 6061-T6 aluminum, two internal supports made of 0.125 inch by 1.0 inch steel, four skid clamps made of 1.0 inch by 0.0625 inch steel, and two 36 inch long skids made from 0.875 inch diameter stainless steel tubing. Figures 13 depicts the three renditions of the skid support design with the final design providing maximum tread width and minimum ground clearance. Figure 14 shows a side view of the skid system attached to the helicopter chassis. Figure 15 depicts the completed landing gear system mounted on the chassis.

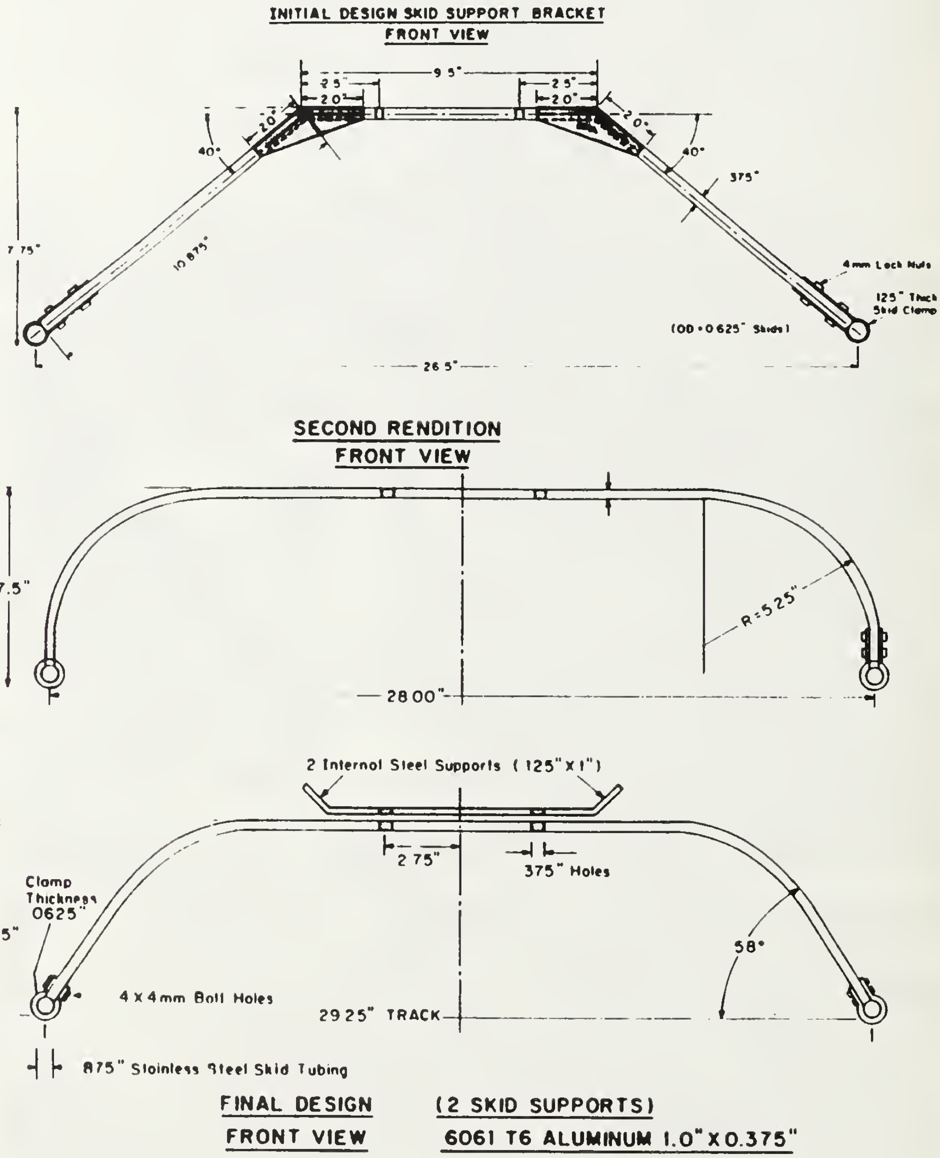


Figure 13. Three Renditions of Skid Support Design

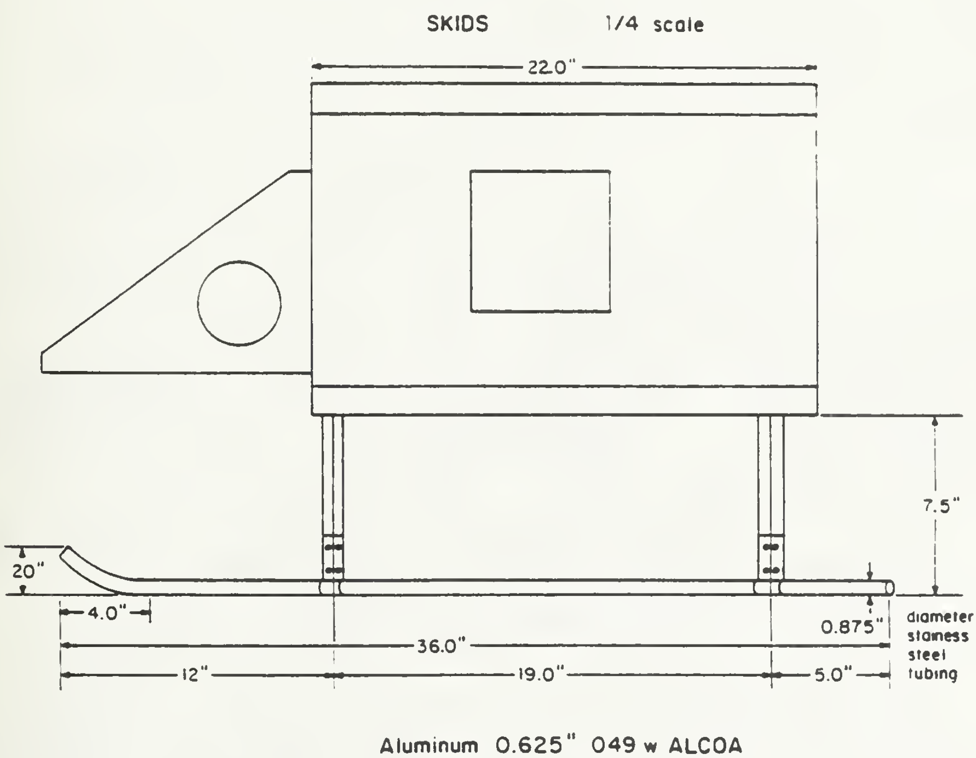


Figure 14. Side View of Skid System Attached to the Chassis

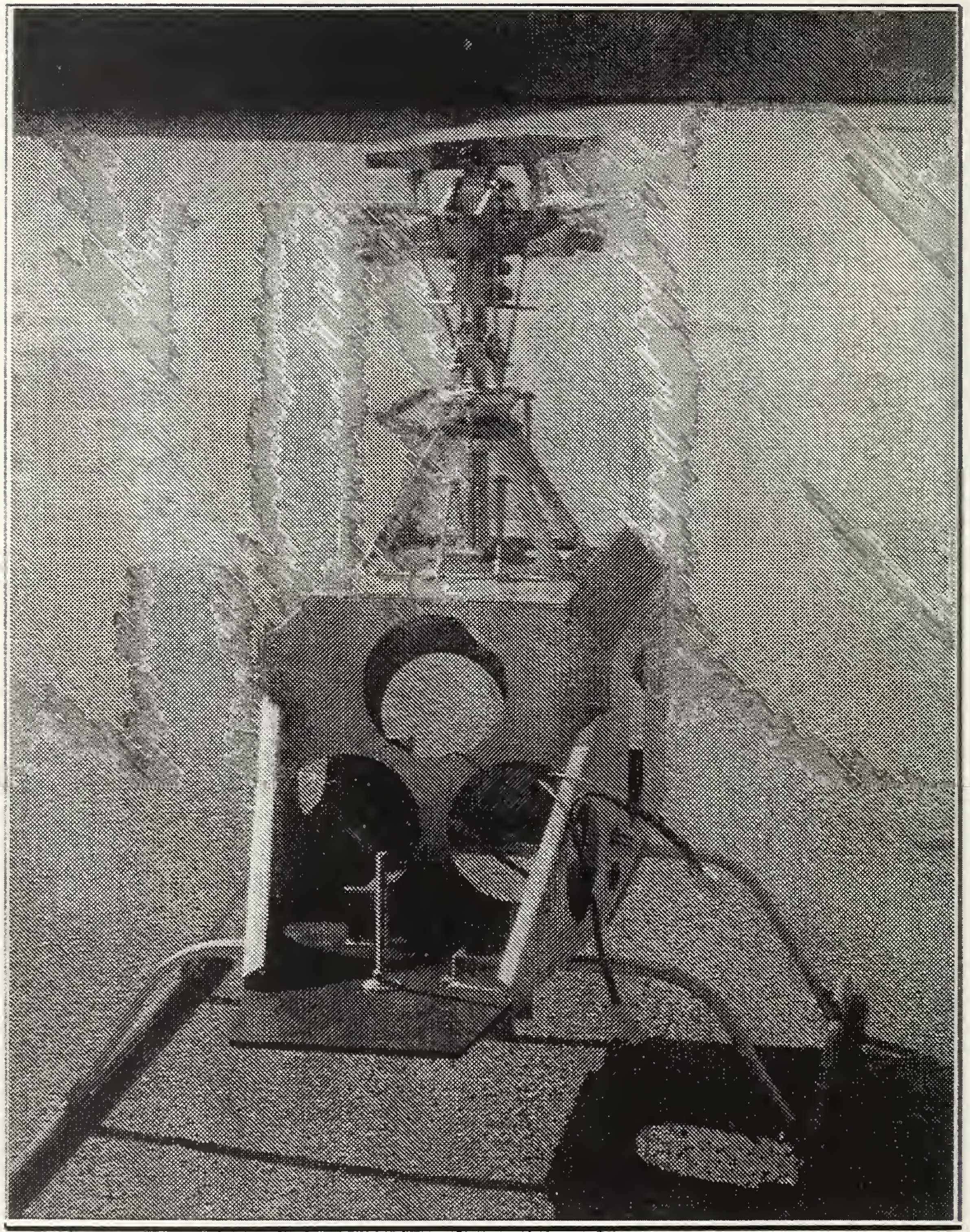


Figure 15. Final Skid Landing Gear Assembly

B. ENGINE MOUNT SYSTEM AND TRANSMISSION COUPLING

In order to correct for excessive friction, high temperatures and high stress encountered in the area of the engine shaft and main transmission shaft coupling, a three piece mount system and a needle bearing were designed and installed. With the needle bearing installed instead of the brass bushing used in the original design, engine alignment became a critical factor. The purpose of the three piece mount system was to maintain that alignment and to more rigidly secure the engine to the helicopter chassis.

1. The Needle Bearing

After determining that the engine output shaft could be aligned and held secure inside the main transmission shaft, it was found that the brass bushing could be replaced by a needle bearing packed with high temperature automotive grease designed for operation under extreme pressure. The outer diameter of the engine shaft was measured at 0.625 inches and the inner bore of the main transmission shaft was measured at 0.8125 inches. The depth to which the engine shaft went into the transmission shaft was measured at 0.45 inches. A needle bearing was then found that fit these dimensions and was purchased from Sterling Instruments. [Ref. 6] Figure 16 depicts the needle bearing as well as the grease that was used to pack the bearing. The needle bearing was rated for a maximum speed of 22,000 rpm, maximum dynamic load of 1,290 pounds, and a maximum static load of 1,140 pounds.

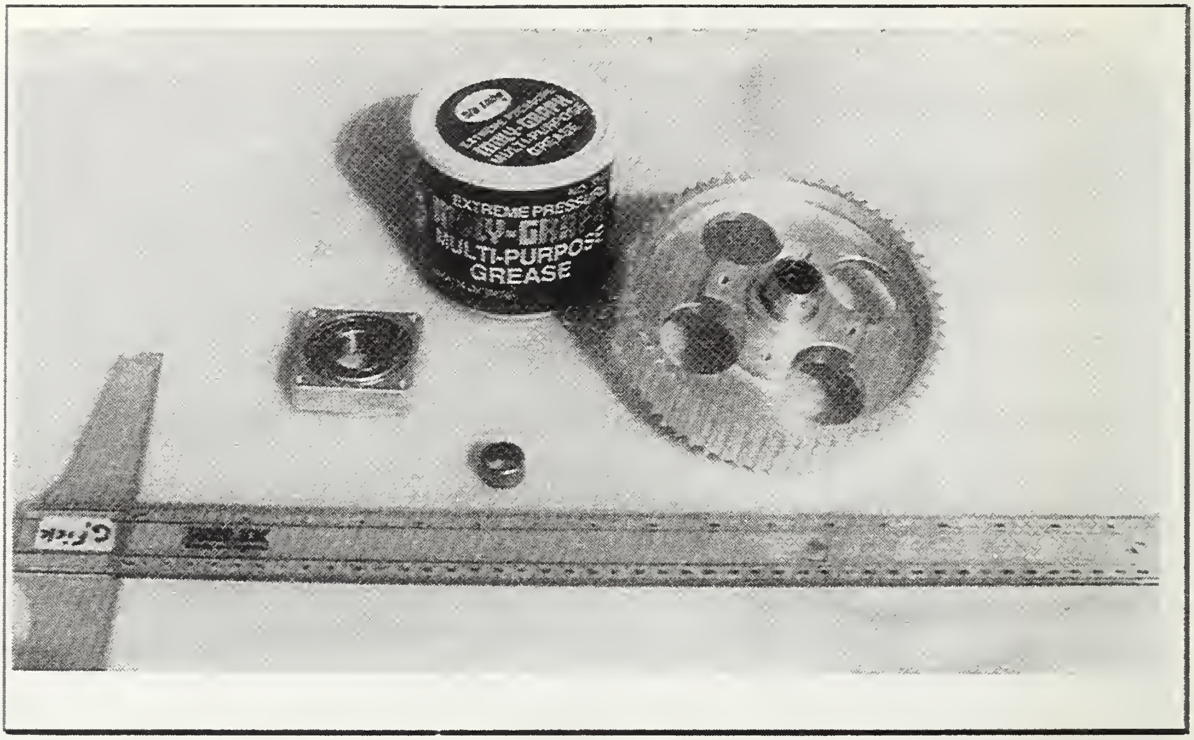


Figure 16. Needle Bearing, Grease, and Transmission Shaft with Bearing Inserted.

2. The Lower Engine Mount System

After the engine shaft was lowered into the the transmission housing (0.1755 inches of spacer shims were installed to ensure separation between the engine clutch assembly and the main transmission), it was carefully aligned and measurements were made of the separation between engine support channels and outer chassis. With these measurements, the two lower engine mounts were designed and fabricated using 6061-T6 aluminum bar that was 0.375 inches thick by 1.5 inches wide. Figures 17 and 18 show a schematic of the two components and the completed components respectively. The grooves were cut to a depth of 0.094 inches to ensure proper spacing between the engine and the transmission. These grooves were designed to hold the channel beam supports that were attached to base of the engine. The backs of the two mounts were bored out at the appropriate locations to ensure they sat flush to the chassis once installed. Figures 19 and

20 depict the spacer shims used to ensure separation between the clutch and transmission and the bores located on the backs of the two mounts.

With the two lower engine mounts placed on the chassis, the engine was lowered into position and realigned. A center punch was used to mark the exact positions of the holes for the engine mount attachment bolts. These holes were then drilled and the lower mounts were loosely fastened to the chassis using the attachment bolts. The engine was again lowered into place and aligned with its channel supports resting in the grooves. A center punch was again used to mark the positions of the four engine attachment bolt holes. The lower mounts were removed and the four holes were milled. Next, the two lower mounts were secured to the chassis with the bolts and locknuts and the holes for the engine attachment bolts were drilled through the chassis. Four steel spacers were machined to decrease the gap between the engine channel supports and the lower mounts. Figure 21 depicts the lower mounts with the channel spacers in position.

Final installation of the lower mounts and engine was next completed. The needle bearing was packed with extreme pressure grease and the spacer shims were lubricated. The engine was lowered into position and aligned with the grooves. Then, the steel channel spacers were placed in position and the four engine attachment bolts were secured. Figure 22 depicts the final lower mount assembly with the engine installed.

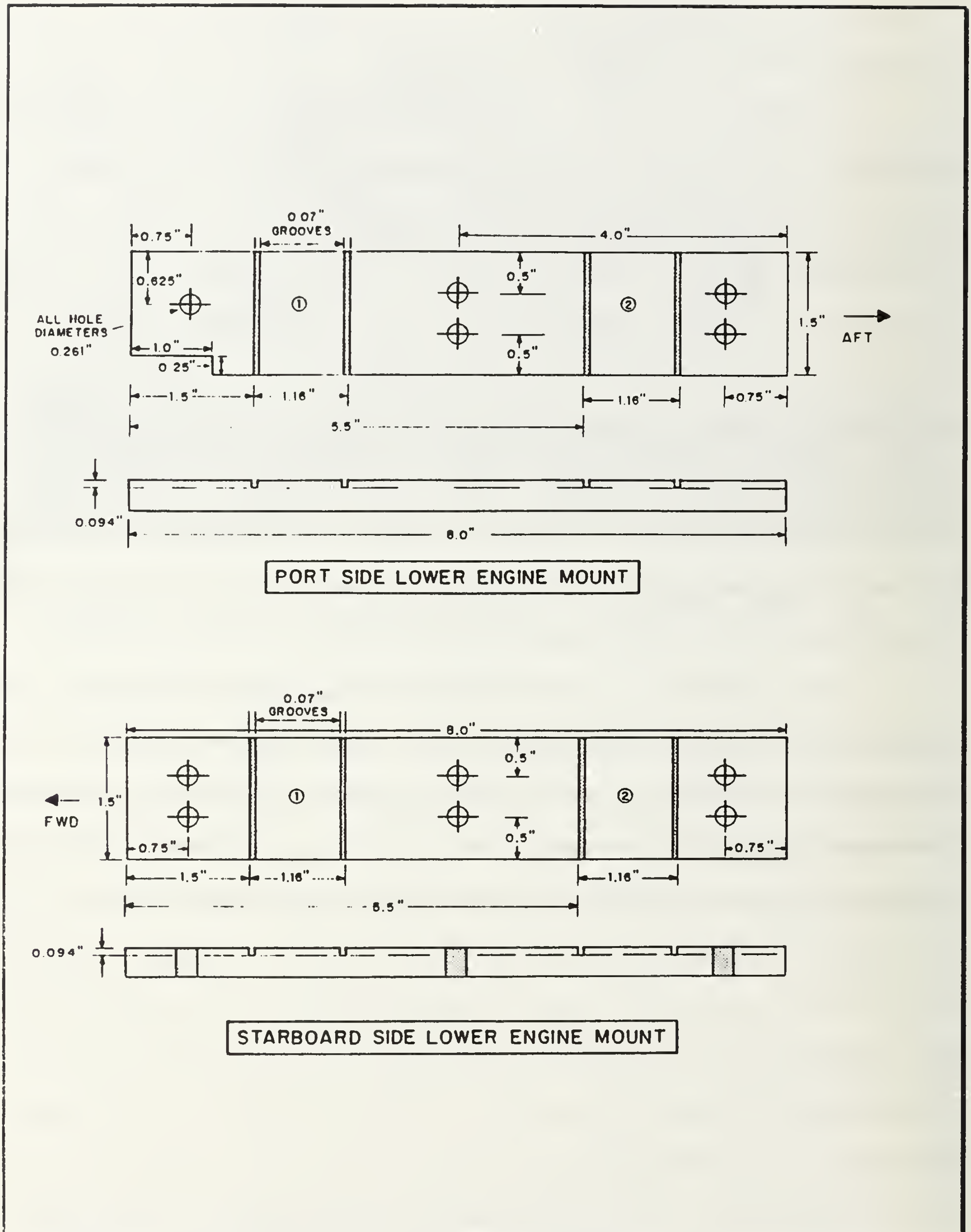


Figure 17. Schematic of Lower Engine Mounts

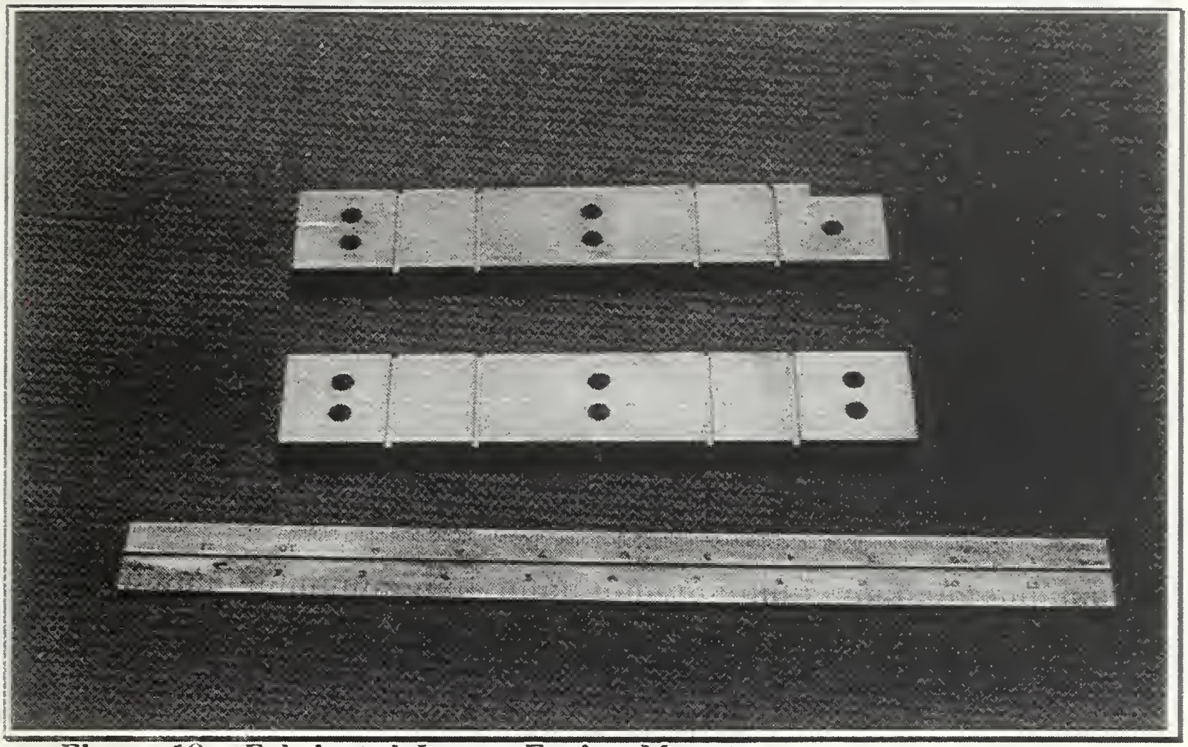


Figure 18. Fabricated Lower Engine Mounts

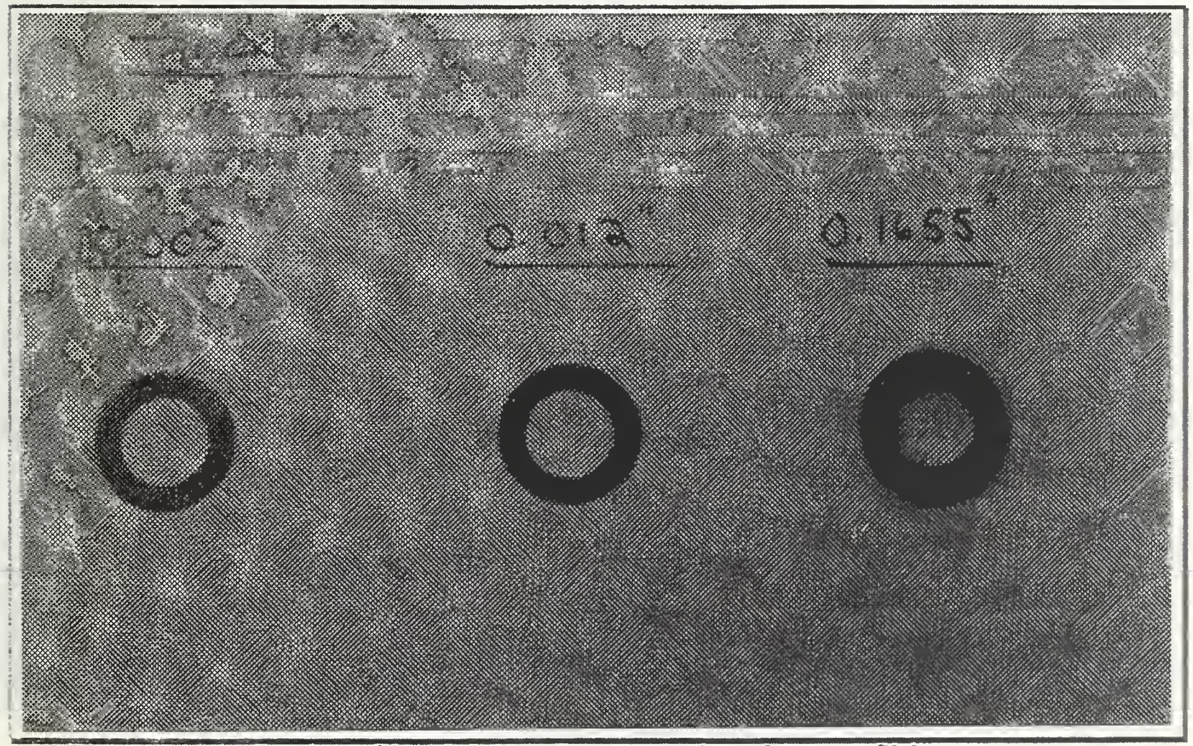


Figure 19. Engine Clutch and Transmission Spacer Shims

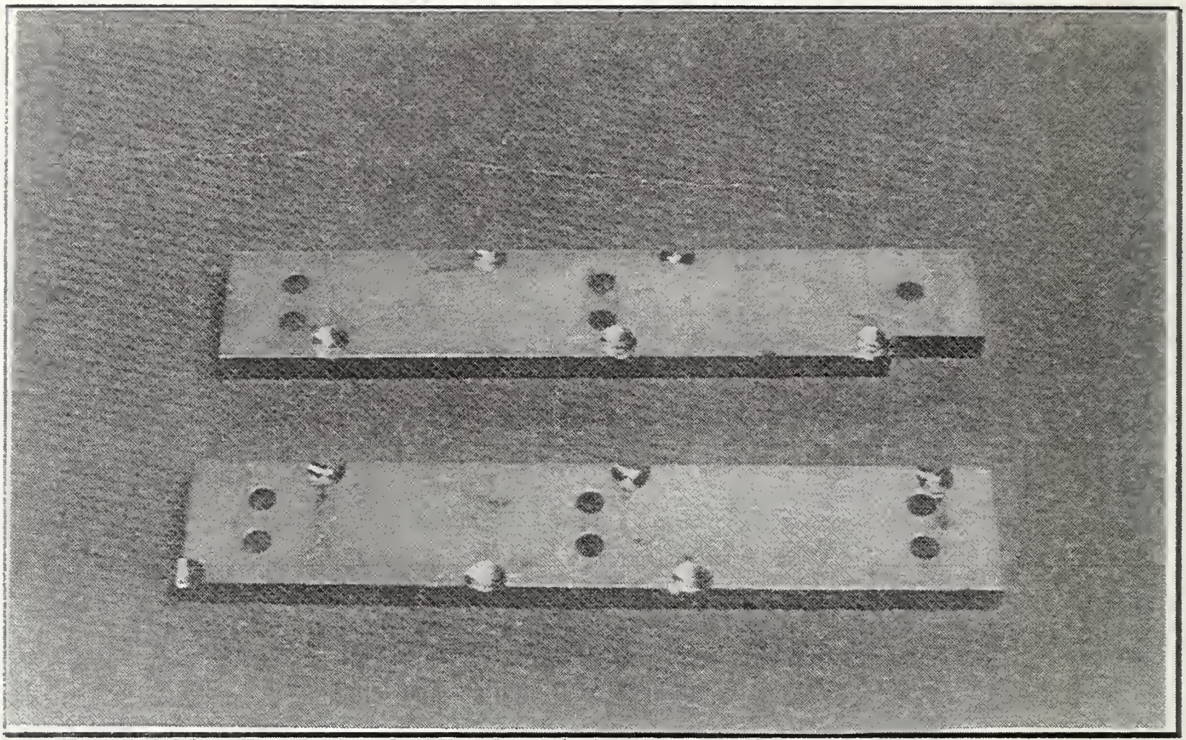


Figure 20. Bores in the Backs of the Lower Mounts

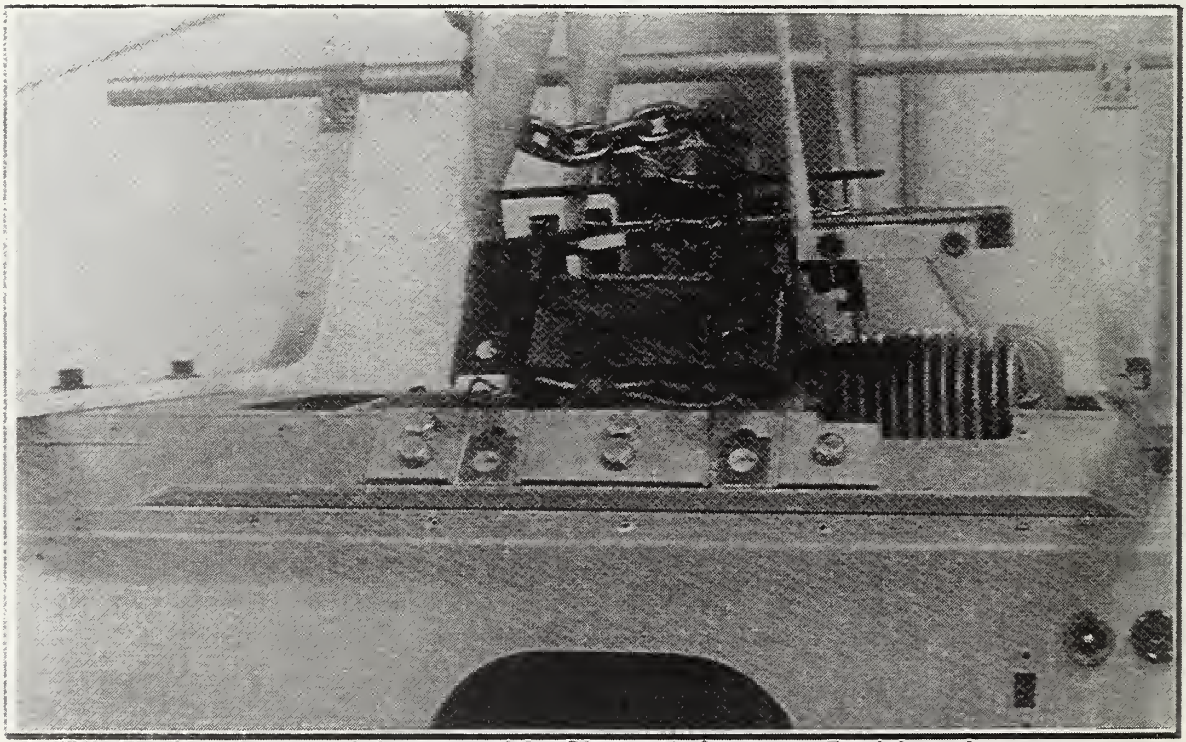


Figure 21. Lower Mounts with Channel Spacers Positioned

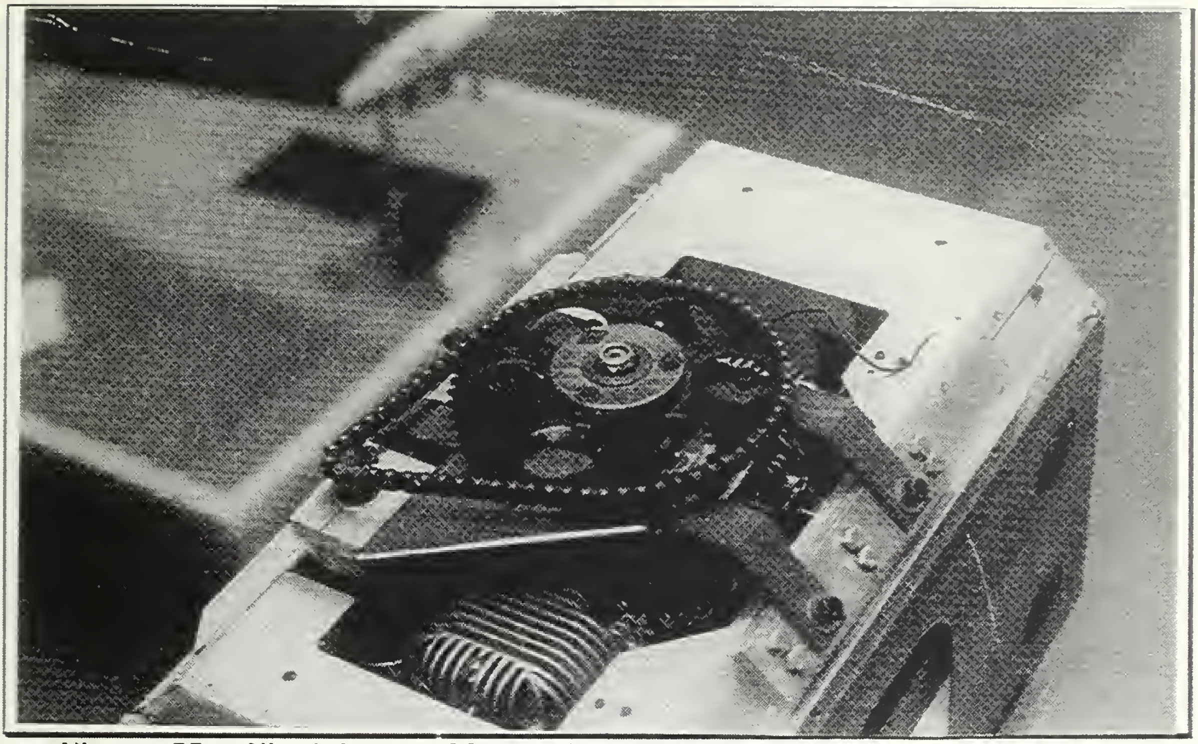


Figure 22. Final Lower Mount Assembly Installed

3. The Upper Engine Mount

In order to maintain engine alignment within the needle bearing during engine operation, an upper engine mount assembly was required to counter torque and longitudinal pulling of the engine transmitted from the belt drive of the main transmission. Figure 23 shows the schematic of this upper mount system, which was fabricated from 1.0 inch angle steel. Figure 24 depicts the upper mount assembly installed in the chassis. With the two upper cylinder head screws from the aft cylinder removed, the upper mount cross member was placed with the two hexagonal sleeves aligned with the screw holes on the engine. Longer head screws were then inserted through the sleeves and tightened with a torque wrench to the required torque value. The two end supports were then fastened to the crossmember and holes were drilled through the chassis for the attachment bolts. The chassis had previously been reinforced by riveting a strip of 0.0625 inch thick sheet aluminum to the exterior of the chassis on both sides. Two bolts were then run through the

supports and chassis and the upper mount assembly was secured to the chassis with locknuts. This design, while providing the necessary support for the engine, was also chosen for its ease of installation and removal. The cross member could be removed by disconnecting its ends from the wall supports and removing the two cylinder head screws.

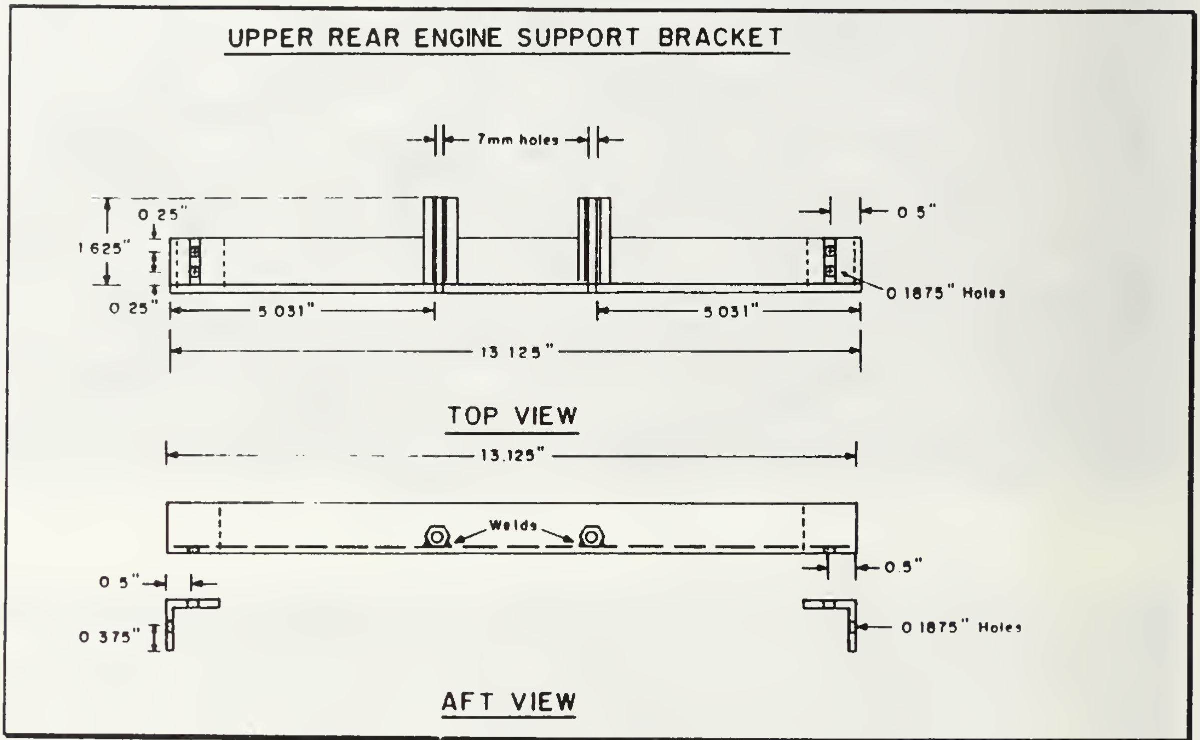


Figure 23. Upper Engine Mount Schematic

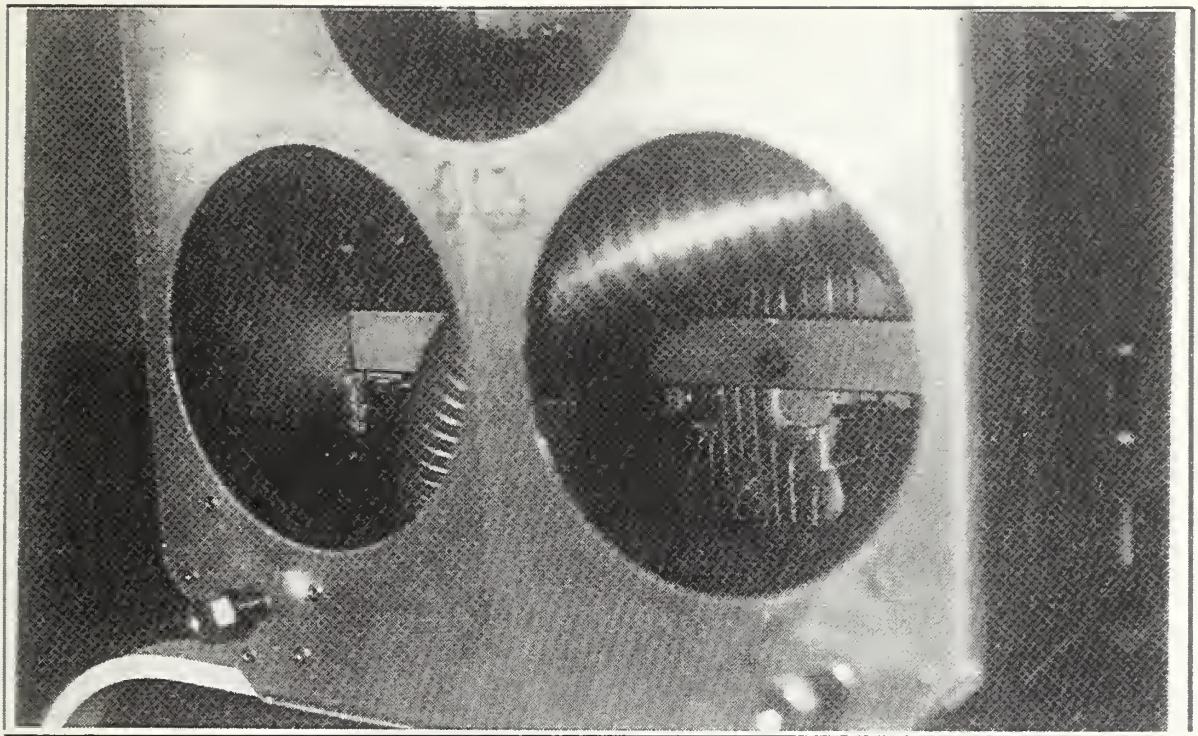


Figure 24. Upper Engine Mount Assembly Installed

C. NOSE AND ELECTRONICS MODIFICATIONS

The nose compartment that was delivered with the helicopter was found to be too small to accomodate the electronics, fuel tank and ballast weights. The plywood deck of the compartment was therefore lengthened 6.0 inches. Figure 25 shows the shematic of the modified nose compartment. Velcro harnesses were installed to secure the fuel tank, batteries, and radio receiver. A solid state rate gyro and a radio controlled magneto-grounding switch were also installed as upgrades to the original design. The grounding switch was installed for safety purposes, providing an emergency engine shutdown capability. Figure 26 depicts the final layout of the nose compartment.

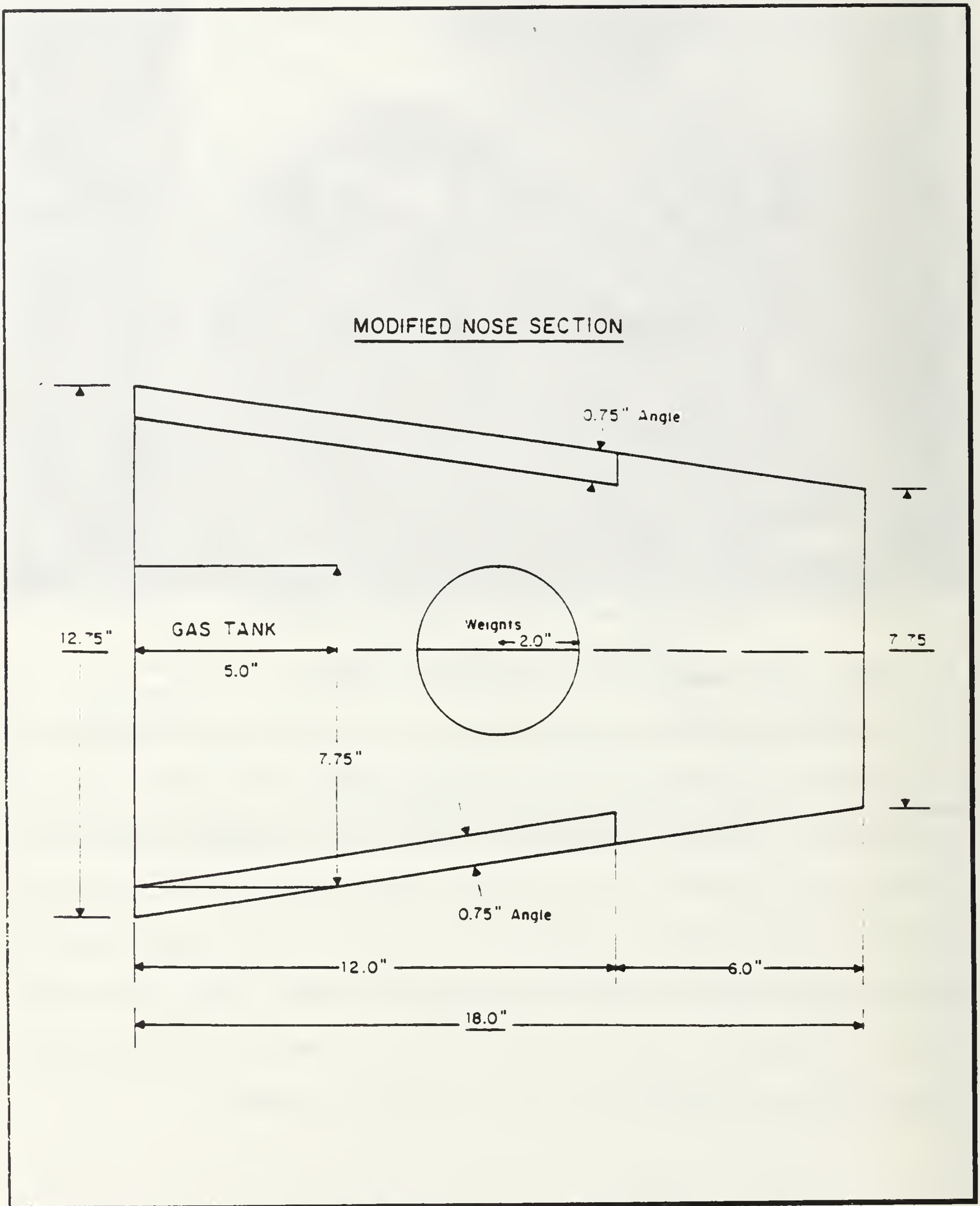


Figure 25. Schematic of Enlarged Nose Compartment

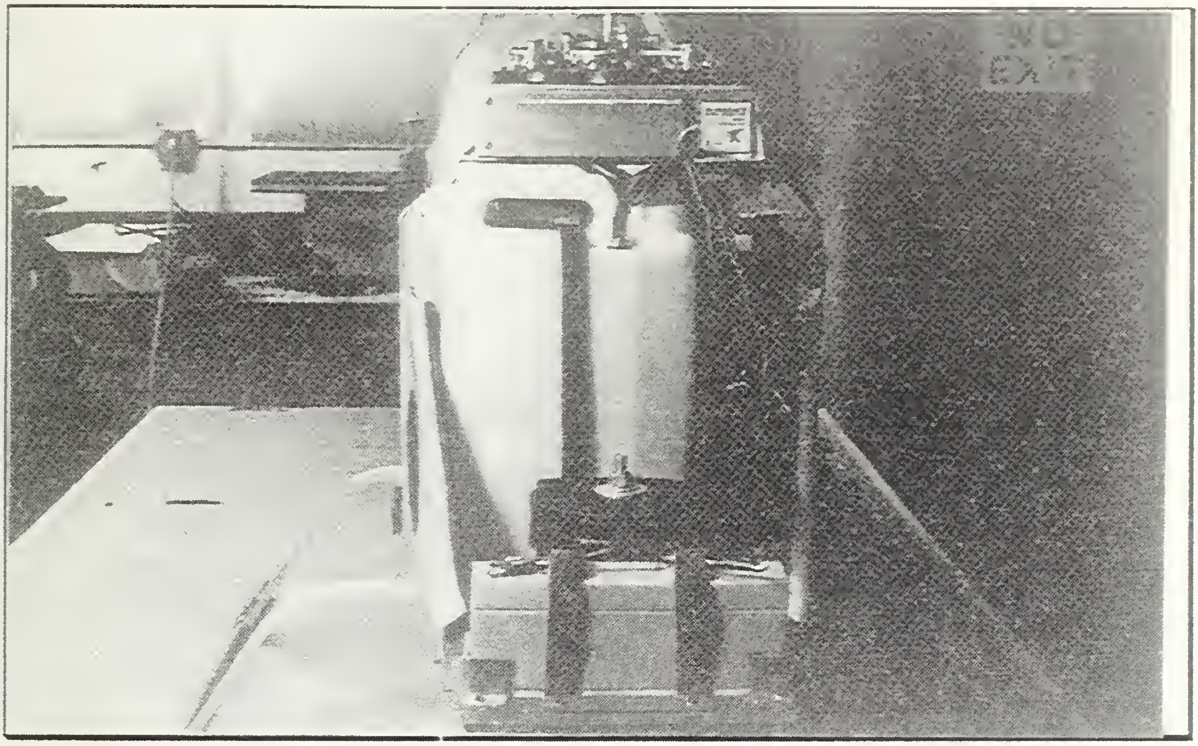


Figure 26. Completely Assembled Nose Section

D. THE ROTOR HEAD ASSEMBLY

Two modifications were incorporated in the main rotor head assembly. Main rotor blade lead-lag links were fabricated from steel turnbuckles, since none were provided with the helicopter. Figure 27 depicts one of the lead-lag links after installation. Cyclic control power and stabilization was provided by incorporating a Bell-Hiller stabilizer paddle and weight assembly. To prevent the weighted paddles from seperating from the aircraft due to centrifugal force, the ends of the bars were threaded and locknuts were attached. Two set screws above and below the attachment points of the two paddles also aid in securing them. Figure 28 depicts one of the Bell-Hiller stabilization paddles with the locknut secured.

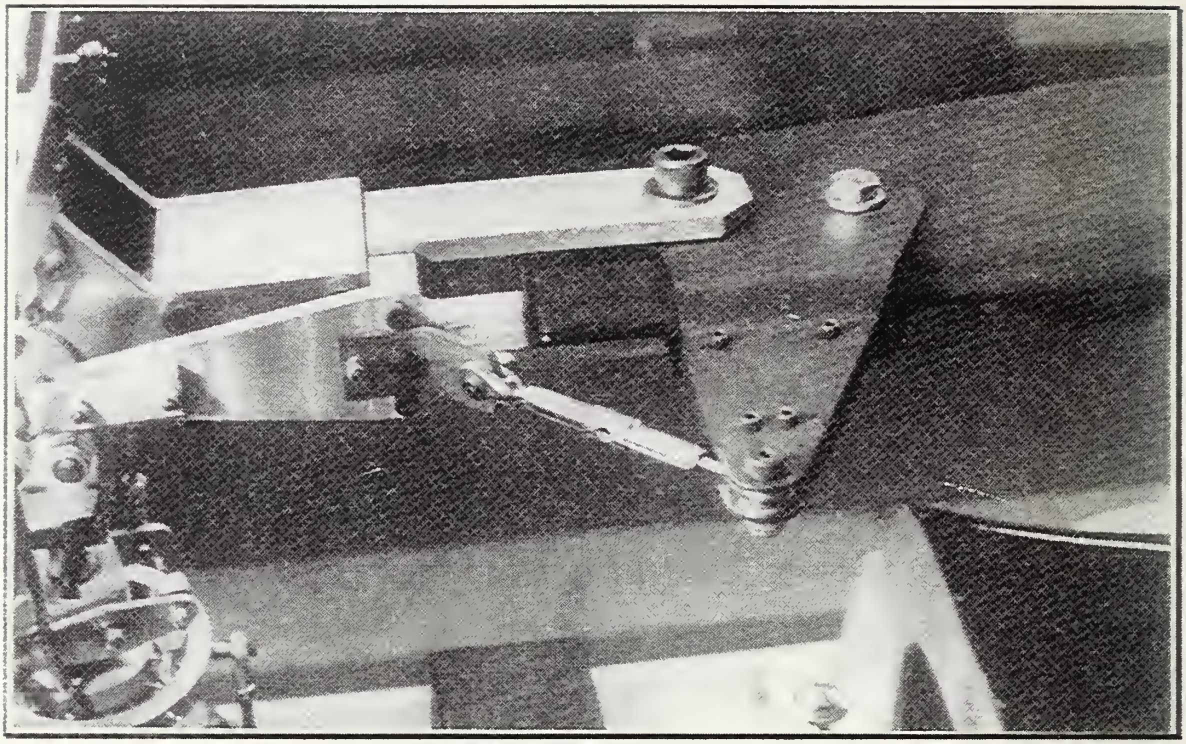


Figure 27. Main Rotor Blade Lead-Lag Link

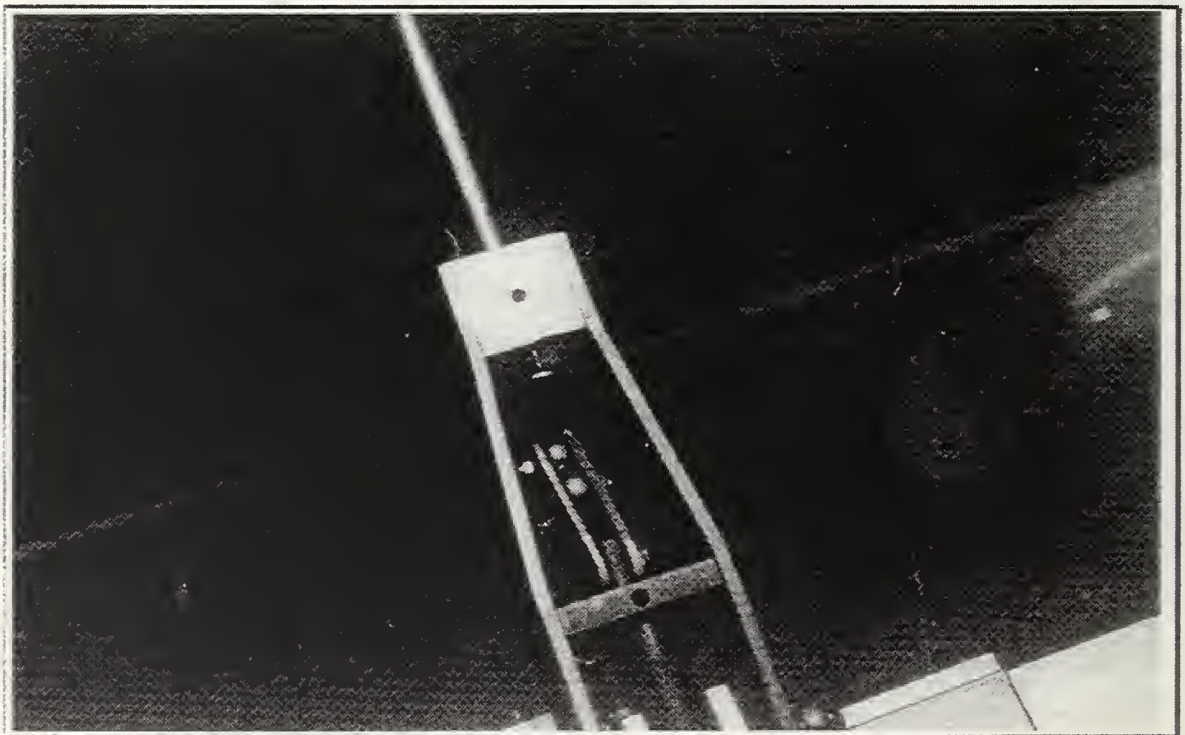


Figure 28. Bell-Hiller Stabilization Paddle with Locknut

V. FINAL ASSEMBLY & FLIGHT PREPARATION

Once all the design modifications were completed and installed, the fiberglass fuselage and tailboom had to be fit to the chassis, repaired, primed and painted. Also, before the static ground testing of the RPH, the main and tail rotors needed to be rigged for flight and the control radio adjusted. A listing the final specifications has been included in Appendix D.

A. FUSELAGE INSTALLATION

The tail section was first secured to the aft end of the chassis, followed by the forward fuselage being slid over the chassis to where it overlapped the tail section by 0.25 inches. With seven dzus fasteners previously riveted to the chassis, holes were drilled for the male ends of the fasteners. These male ends were then riveted in place and the forward fuselage was fastened to the chassis. Figure 29 depicts this fitting process.

Access ports previously cut into the forward fuselage on the port side were misaligned and had to be patched and recut. Figure 30 depicts the forward fuselage after patching. Following this, both the forward fuselage and the tailboom were repaired for pinholes with a fiberglass sealant. Figures 31 and 32 depict the pinhole repair process of the fuselage and tailboom respectively.

Final body work involved recutting the access ports, sanding of the entire fuselage, application of a primer coat, wet-sanding of the aircraft and final coat application. Once the gloss white enamel topcoat had dried, navy blue gloss enamel highlights, striping, and custom decals were added. Figures 33 and 34 depict the resultant fuselage and tailboom paint job.

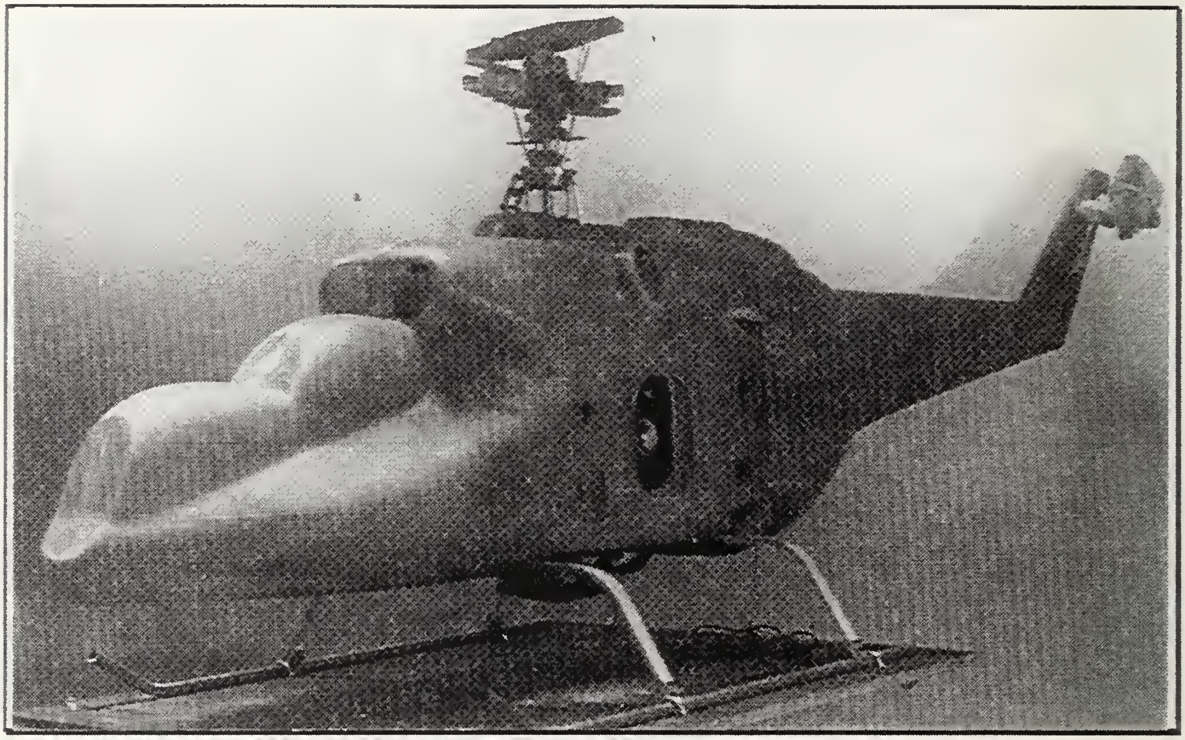


Figure 29. Fuselage Being Fit to the Chassis

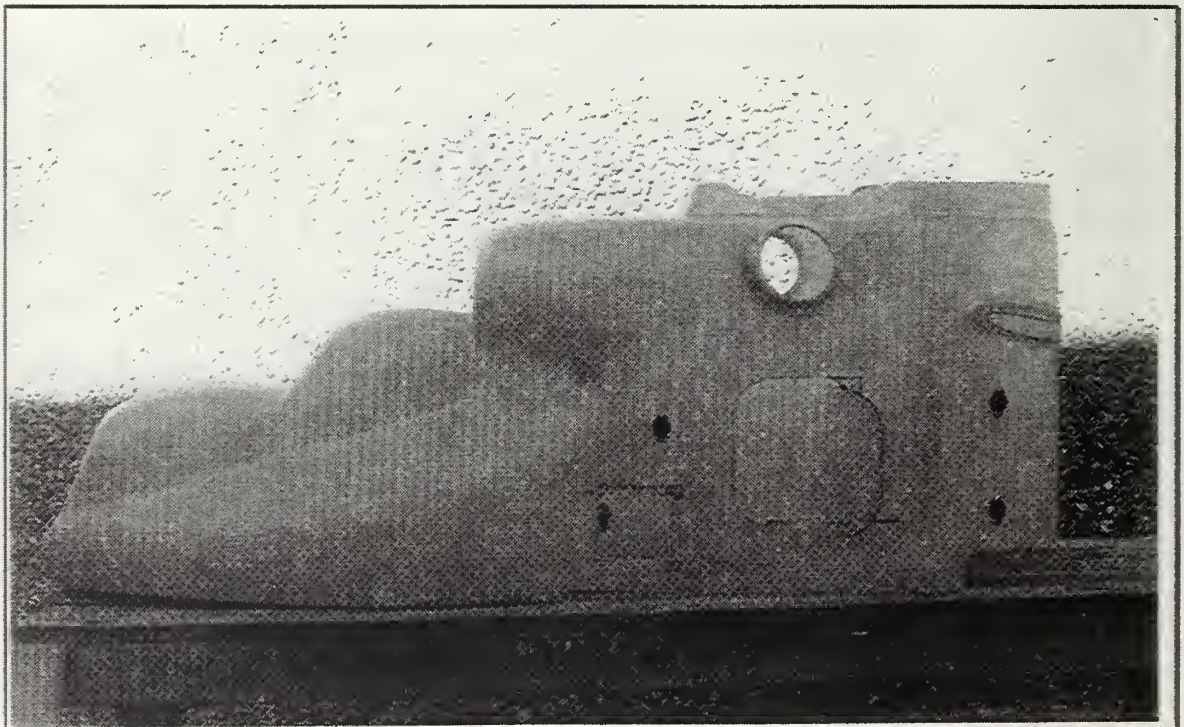


Figure 30. Forward Fuselage Patching

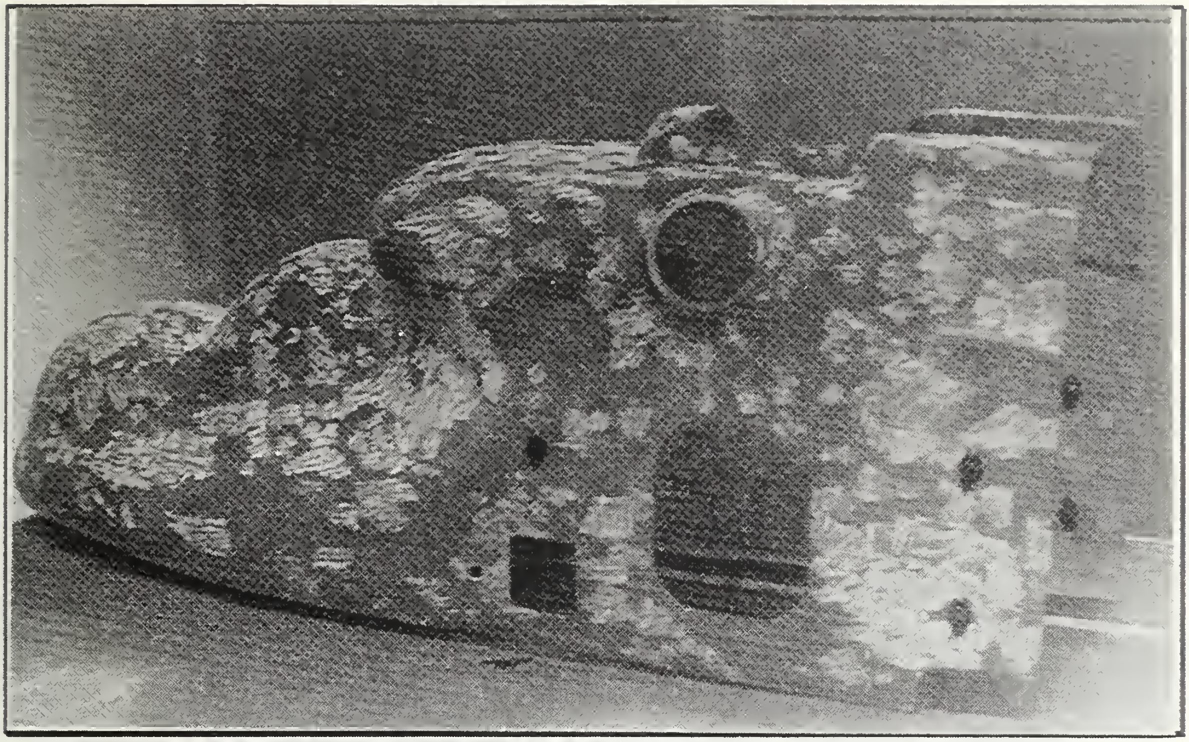


Figure 31. Forward Fuselage Pinhole Repair

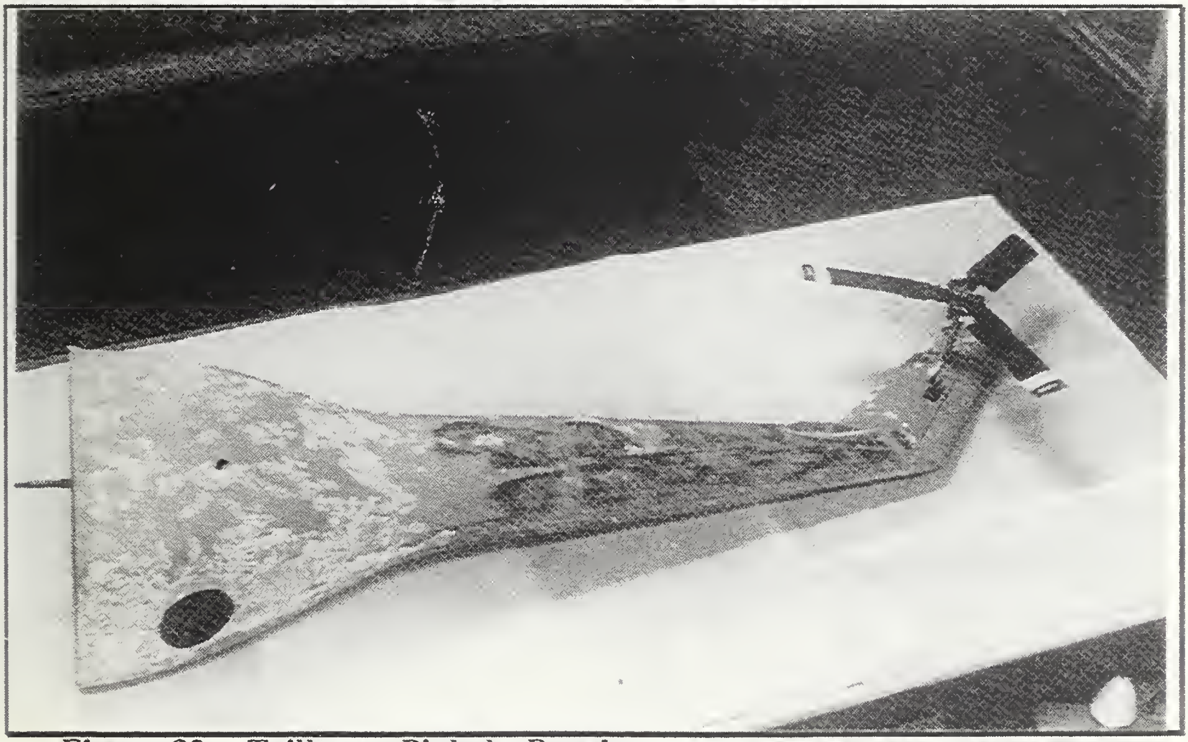


Figure 32. Tailboom Pinhole Repair

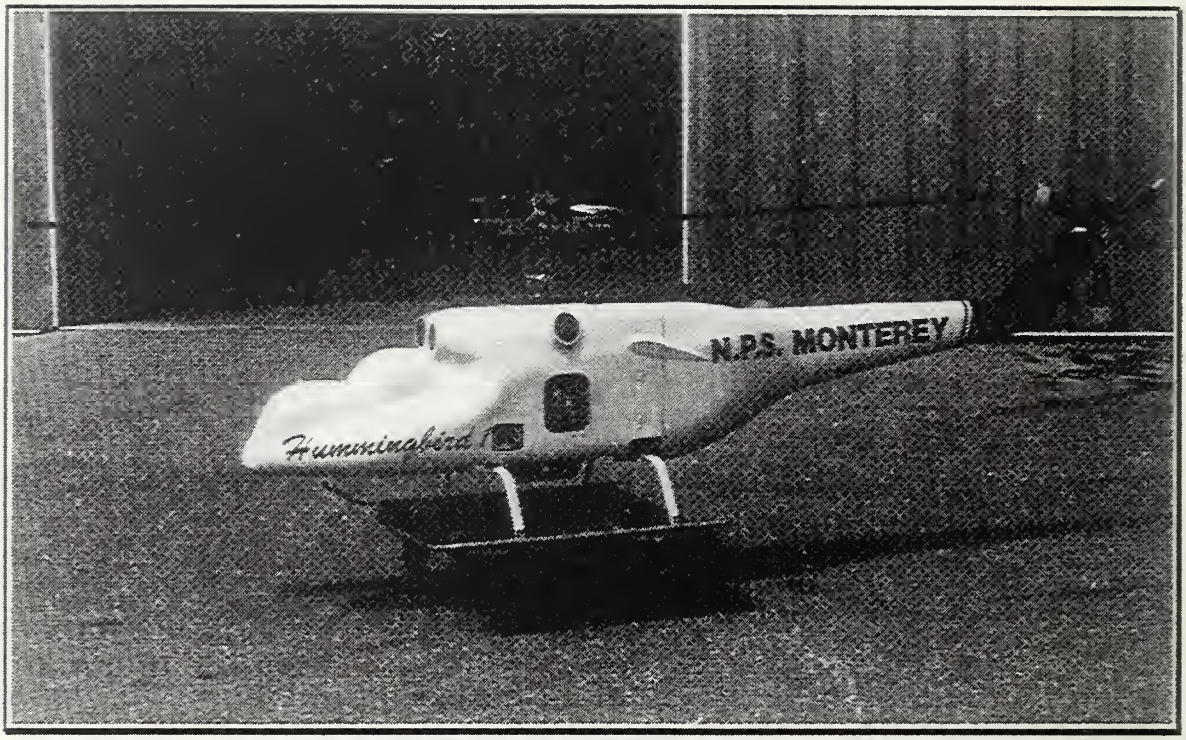


Figure 33. Final Paint Job, Port Side

Figure 34. Final Paint Job, Starboard Side

B. PREFLIGHT RIGGING OF THE ROTOR SYSTEMS

Prior to static ground tests of the helicopter, both main and tail rotor systems were fine tuned and rigged according to data provided by Gorham Model Products, included in Appendix D. During this rigging process, the Futaba radio transmitter was adjusted and all batteries for the helicopter, the radio, and the starter were charged. Also, the starter cables were lengthened and connected to a toggle switch to start the helicopter remotely. Figure 35 shows the radio transmitter.

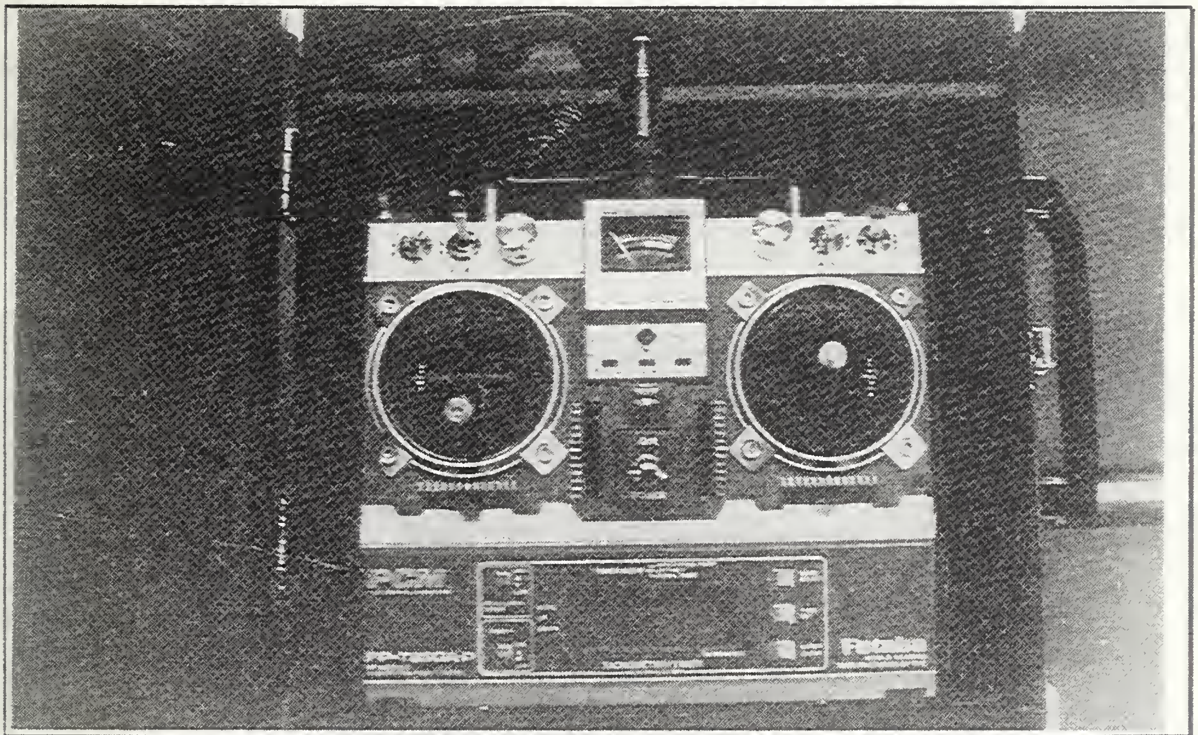


Figure 35. Futaba Radio Transmitter

VI. GROUND TESTS

Static ground tests were conducted after the completion of the assembly of *Hummingbird* 1 including testing and break-in of the new engine, blade tracking and balancing, checking autorotative capabilities, and checking the structural integrity of the helicopter. The engine, having never been run, was required to be run statically for two hours to ensure it would be properly broken-in according to the Westlake operators manual [Ref. 3] in Appendix C. Tests were conducted in the outdoor engine test area behind Building 230 at the NPS Annex. Due to lack of cooling air to the cylinder heads when operating the helicopter statically at idle speeds, each run was limited to between 5 and 10 minutes duration to avoid overheating the engine. Four successful runs totalling approximately 21 minutes have been completed. During these runs, blade tracking and blade balancing were completed and hover power was achieved. The emergency engine cut-off switch was used successfully on all engine shutdowns. During one shutdown from idle power, the time for the rotors to completely stop was measured at approximately 2 minutes in an attempt to ascertain whether the vehicle could successfully autorotate. Also, during early test runs, several bolts and assemblies were found to have worked themselves loose and were refastened securely using lock thread compound. Figure 36 depicts the test facility with the RPH mounted on the static test stand. Figue 37 depicts the test stand itself.

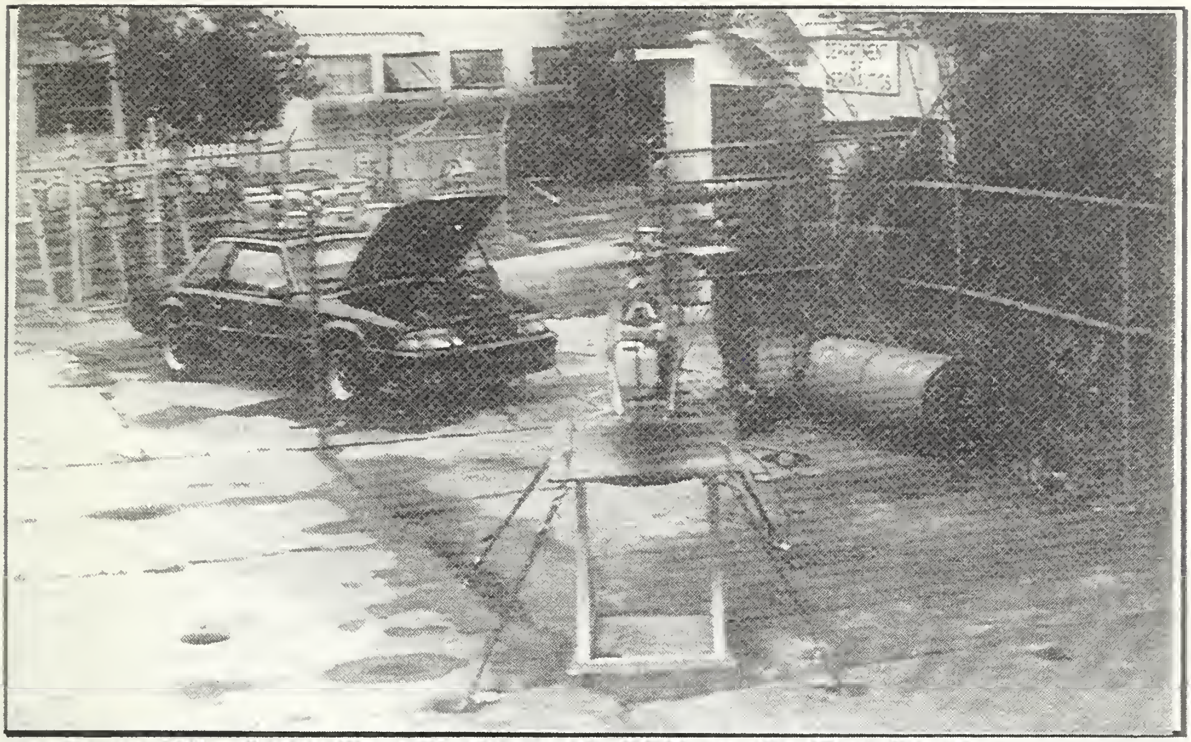


Figure 36. Static Test Facility with RPH on the Test Stand

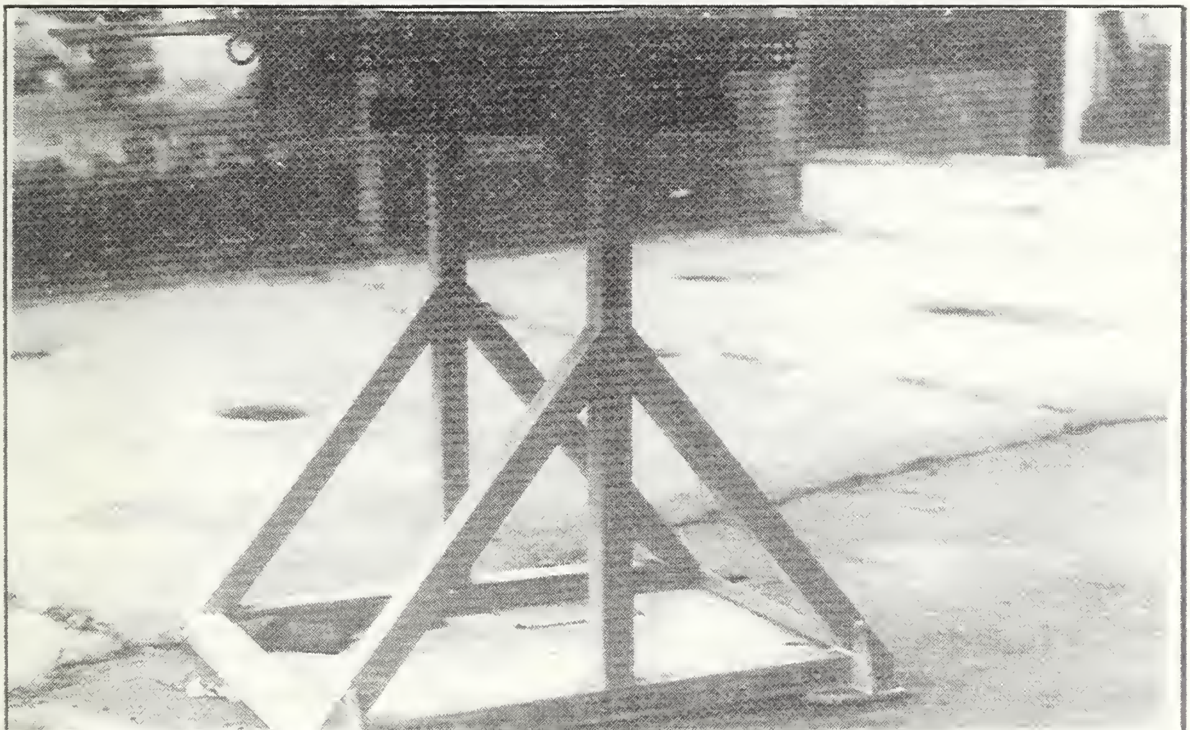


Figure 37. Static Ground Test Stand

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The Gorham Model Products Hind-D remotely piloted helicopter was modified to better suit the needs of the Naval Postgraduate School and to correct for major design deficiencies found through careful inspection of the original helicopter. The landing gear system was improved to provide a load absorbing capability through the use of high strength aluminum skid supports and the tread width was increased 140%, resulting in a 40 degree static tipover angle. A rigid engine mount system combined with the incorporation of a needle bearing between the engine drive shaft and the main transmission shaft greatly reduced the severe friction and high temperatures associated with the original design. Enlarging the nose compartment provided ample room for the electronics, fuel tank, and ballast weights. Also, all ballast weights were consolidated to one location to simplify weight and balancing of the helicopter. Updates to the electronic components, including the solid state rate gyro for yaw control, and the incorporation of a remotely controlled engine shutdown switch improved the safety of vehicle operations. The addition of locknuts to the inboard ends of the Bell-Hiller stabilization paddles also improved the safety of helicopter operations. A completely assembled and ground tested RPH was produced that can serve as a flight-capable test platform for future research projects including, the installation of a NOTAR tailboom and active vibration reduction through HHC.

To facilitate the possible future assembly of a second *Hummingbird* helicopter and to provide all information necessary for the maintenance and repair of *Hummingbird* 1, this thesis document was compiled and organized to act as an operators manual for the helicopter. Schematics for all design modifications were included, accompanied by a parts

inventory, engine removal procedures, engine maintenance procedures and rotor rigging data.

B. RECOMMENDATIONS

Although several of the original design deficiencies have been corrected, seven additional modifications were identified as necessary for future research with the helicopter. In addition, three recommendations surfaced that would improve the laboratory facilities.

1. Recommendations for the Helicopter

a. Redesign of Main Transmission

The gear reduction necessary to provide realistic rotor blade Reynolds numbers for future work in HHC requires that one of the large gears in the main transmission be reduced in size. Although the engine clutch allows the rotor systems to freewheel upon engine shutdown, the helicopter should be analyzed for its autorotative capability and, if necessary, a one-way bearing should also be installed that allows both rotors to freewheel in case of engine failure. Allowing both rotors to freewheel provides the operator with directional control during such emergencies. Figure 38 depicts the main transmission as viewed from the bottom access port in the chassis.

Although a new mounting system was designed and installed to alleviate the extreme temperatures and friction in the area of the interface between the engine and transmission shafts, a permanent couple must be designed to completely correct this design flaw. The scorched shaft and brass bushing from the chassis of the RPH that had flown were loaned to the Department of Material Sciences at NPS where it will be analyzed to determine the stresses involved. The results of this analysis should aid in designing or obtaining a permanenent coupling suitable for the helicopter.

b. Design a Three Bladed Rotor Head

In order to begin research in the area of HHC, a three-bladed rotor head assembly must necessarily be designed and fabricated. The design alone comprises a thesis project.

c. Build *Hummingbird* 2

During the initial inventory of parts and assemblies delivered from GMP and the disassembly of the second helicopter that had flown, it was discovered that enough parts remain to build a second RPH. Assembly of a second helicopter would greatly expand the research capabilities of the department, but also would drastically reduce the supply of spare and replacement parts available.

d. Design and Fabricate Horizontal Stabilizers

The helicopter currently is capable of hovering flight only. Horizontal stabilizers must be designed, fabricated and installed on the tailboom of the helicopter. Incorporation of an adjustable trim mechanism would also be preferable.

e. Modify Forward Fuselage

The forward fuselage currently on the helicopter needs to be modified to increase the internal volume of its nose area. Currently, this assembly requires excessive force to align the fasteners of the fuselage with the chassis. Also, increasing the size of the front end of the fuselage will afford more space for payloads in the nose compartment.

f. Spline Starter Shaft and Gear

During the ground tests of the RPH, the output gear for the starter motor repeatedly worked itself free due to its only being fastened with a set screw. Milling or drilling an indentation in which the set screw could seat would alleviate the problem.

g. Continue Towards NOTAR and HHC Research

With a suitable flight test platform available, research in the areas of NOTAR and HHC can progress. Figure 39 depicts NOTAR tailboom assemblies that have been designed and fabricated for installation on the *Hummingbird* RPH by students including LT. L. M. Borno [Ref. 7] and LT. Robert King. [Ref. 8]

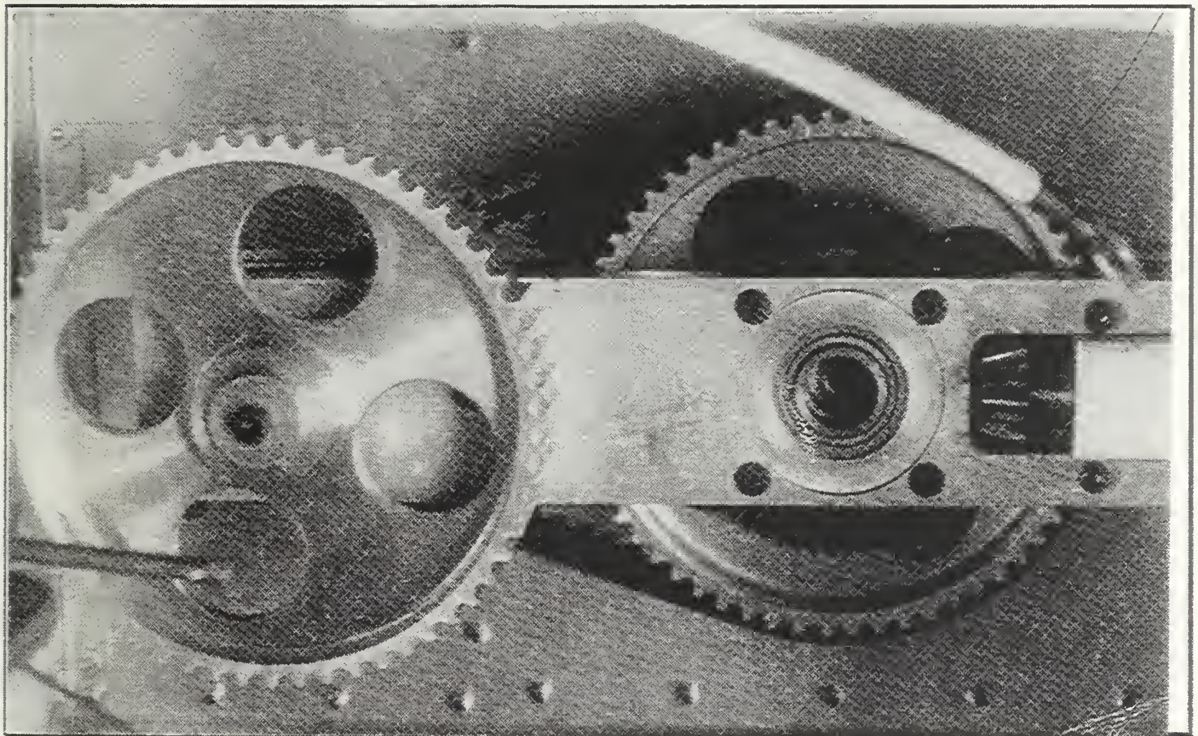


Figure 38. Main Transmission

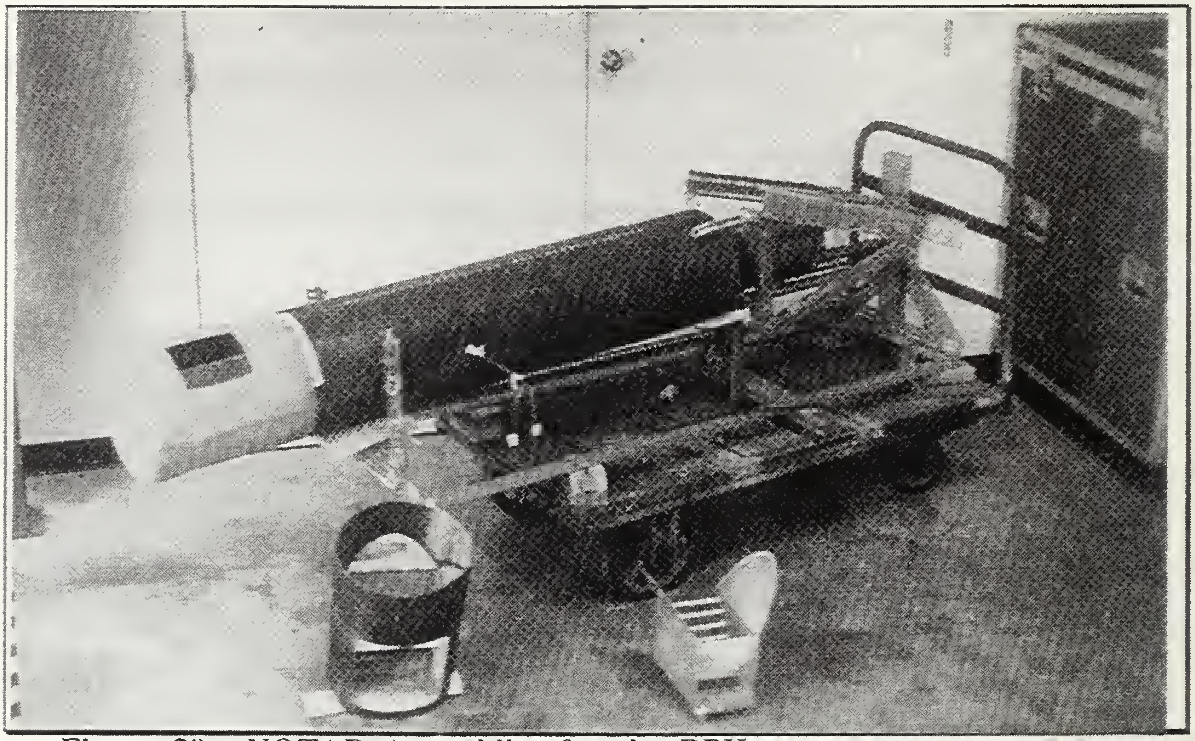


Figure 39. NOTAR Assemblies for the RPH

2. Recommendations for the Facilities

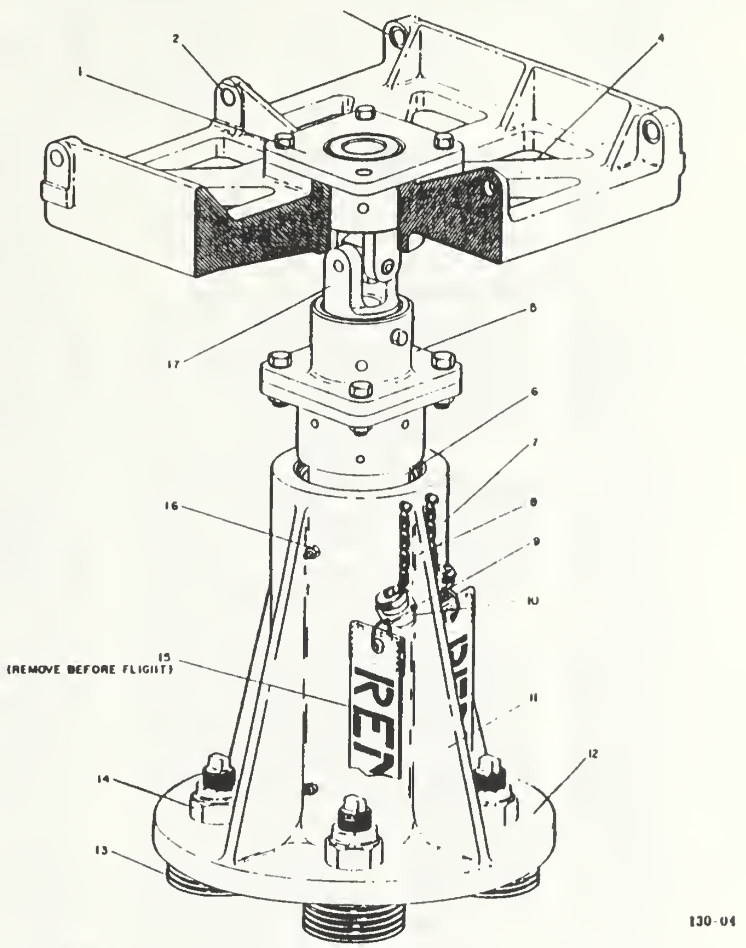
a. Create RPH laboratory in Building 230

Adequate space has been provided in Building 230 at the NPS Annex for a remotely piloted helicopter laboratory. The laboratory will need to be supplied with adequate tools, and manned by a dedicated RPH technician. Expanding research both in fixed wing and rotary wing remotely piloted vehicles will soon limit student accessibility to the current sole technician. Associated with this laboratory, the outdoor engine test facility located behind Building 230 should be maintained and used for all static tests.

b. Design and Fabricate a Hovering Fixture

A hovering fixture similar to that developed at HAWC WD China Lake should be designed and fabricated for use with the 1/4 scale helicopter. This mechanism, while eliminating any risk of crashing the RPH, would allow safe dynamic testing of the current helicopter and future modifications of the vehicle in hovering flight. The fixture at China

designed for helicopters in excess of 13,000 pounds gross weight. [Ref. 9] A similar stand with a capacity of 300 pounds or less should be designed and built. Figure 40 depicts the hovering fixture.



1. Upper flange
2. Pad eye bushing (middle)
3. Pad eye bushing (outboard)
4. Saddle
5. Lower flange
6. Piston
7. Identification plate
8. Chain
9. Receptacle
10. Shorting plug
11. Web
12. Base assembly
13. Baxter bolt
14. Nut
15. Warning streamer
16. Lubrication fitting
17. Universal joint

Figure 40. Hovering Fixture

APPENDIX A: PARTS INVENTORY AND LIST OF AREA SUPPLIERS

GMP PARTS INVENTORY

PART #	LOCATION	ITEM	QTY PER SHIP	DRWG #
TC 040	CNTR FLTR CNTRLS	Pitch Belcrnk Pivot	2	GTC-040
TC 041	CNTR FLTR CNTRLS	Pitch Locating Arm	2	GTC-041
TC 042	CNTR FLTR CNTRLS	Locating Arm Block	1	GTC-042
TC 043	CNTR FLTR CNTRLS	Arm Pivot Shaft	1	GTC-043
TC 044	CNTR FLTR CNTRLS	Mntg Bracket-Side	2	GTC-044
TC 045	CNTR FLTR CNTRLS	Mntg Bracket-Bottom	1	GTC-045
TC-047	CNTR-FLTR CNTRLS	Pitch Bell Crank	1	GTC-047
TC 048	CNTR-FLTR CNTRLS	Pitch Lever	1	GTC-048
TC 049	CNTR FLTR CNTRLS	Bearing	6	GTC-049
TC 050	CNTR FLTR CNTRLS	Back Up Plate	1	GTC-050
TC-051	CNTR-FLTR CNTRLS	Pitch Lever	1	GTC-051
TC 053	CENTER SECTION	SWASHPLATE		GTC-053
TC 054	CNTR SWASHPLT	Inner Ring	1	GTC-054
TC 055	CNTR SWASHPLT	Outer Ring	1	GTC-055
TC 056	CNTR SWASHPLT	Bearing	1	GTC-056
TC-057	CNTR-SWASHPLT	Pivot Bearing	1	GTC-057
TC 063	CENTER SECTION	RADIUS ARM		GTC-063
TC 064	CNTR RADS ARM	Radius Arm (A)	2	GTC-064
TC 065	CNTR RADS ARM	Mounting Block	1	GTC-065
TC 066	CNTR RADS ARM	Pivot Block	1	GTC-066
TC 067	CNTR RADS ARM	Spacer Block-Small	1	GTC-067
TC 068	CNTR RADS ARM	Spacer Block-Large	1	GTC-068
TC 069	CNTR RADS ARM	Cross Member	1	GTC-069
TC-070	CNTR RADS ARM	Bearing	2	GTC-070
TC 071	CNTR RADS ARM	Radius Arm (B)(*GTC-064)	2	GTC-071
TC 072	CNTR RADS ARM	Bearing Spacer	6	GTC-072
TC-073	CTRR RADS ARM	Bearing	6	GTC-073
TC 076	CENTER SECTION	PUSHRODS		GTC-076
TC 077	CNTR PSHRDS	Pushrod 5"	3	GTC-077
TC 078	CNTR PSHRDS	Pushrod 6.1"	1	GTC-078
TC 079	CNTR PSHRDS	Pushrod-5.3"	1	GTC-079
TC 080	CNTR PSHRDS	Pushrod 5.5"	1	GTC-080
TC 081	CNTR PSHRDS	Ball End-Right	12	GTC-081
TC 085	CNTR-PSHRDS	Pushrod 1.81"	1	GTC-085
TC 086	CNTR PSHRDS	Pushrod 1.15"	1	GTC-086

GMP PARTS INVENTORY

TC 090	CENTER SECTION	RADIO		GTC-090
TC 091	CNTR RADIO	Transmitter unit	1	GTC-091
TC 092	CNTR RADIO	Receiver	1	GTC-092
TC 093	CNTR RADIO	Servo-Small	3	GTC-093
TC 094	CNTR RADIO	Switch-Receiver	1	GTC-094
TC 095	CNTR RADIO	Servo-Large	3	GTC-095
TC 096	CNTR RADIO	Gyro	1	GTC-096
TC 097	CNTR RADIO	Switch Gyro	1	GTC-097
TC 098	CNTR RADIO	Battery-12 Volt	1	GTC-098
T 100		BIRD D COMPLETE*		GT-100
T 100		BIRD D COMPLETE**		

* Crated & complete.
** Ready for final assembly, less radio Rx & Tx.

PLUS THE FOLLOWING PARTS

TF-001	FRONT FUSELAGE	F/G Shell	1	GTF-001
TF 002	FRONT FUSELAGE	Dzus Fastener Stud	8	GTF-002
TF 003	FRONT FUSELAGE	Dzus Fastener Weld Plate	8	GTF-002
TC 001	CENTER SECTION	MAIN CHASSIS	1	GTC-001
TC-002	CNTR MN CHASSIS	Side Panels	2	GTC-002
TC-003	CNTR MN CHASSIS	End Panels	2	GTC-003
TC-004	CNTR MN CHASSIS	Bottom Panel	1	GTC-004
TC 005	CNTR MN CHASSIS	Top Panel	1	GTC-005
TC 006	CNTR MN CHASSIS	Corner Panels	4	GTC-006
TC 007	CNTR MN CHASSIS	Corner Panel Braces	2	GTC-007
TC 008	CNTR MN CHASSIS	Tower Panels	4	GTC-008
TC 009	CNTR MN CHASSIS	Tower Doubler	1	GTC-009
TC 010	CNTR MN CHASSIS	Servo Tray	1	GTC-010
TC 011	CNTR MN CHASSIS	Front Panel-Rt Side	1	GTC-011
TC 012	CNTR MN CHASSIS	Front Panel-Lft Side	1	GTC-012
TC-013	CNTR MN CHASSIS	Radio Cmprtmnt-Bottom	1	GTC-013
TC 014	CNTR MN CHASSIS	Radio Cmprtmnt-Rear Supt	1	GTC-014
TC 015	CNTR MN CHASSIS	Nose Gear Channel	1	GTC-015
TC-016	CNTR MN CHASSIS	Nose Gear Mount	1	GTC-016
TC 017	CNTR MN CHASSIS	Nose Gear Strut	1	GTC-017
TC 018	CNTR MN CHASSIS	Nose Gear Axel	1	GTC-018
TC-019	CNTR MN CHASSIS	Main Gear Brace	2	GTC-019
TC 020	CNTR MN CHASSIS	Main Gear Strut	2	GTC-020
TC 023	CNTR MN CHASSIS	Shroud Mntg Bracket	2	GTC-023
TC 024	CNTR MN CHASSIS	Cooling Shroud	1	GTC-024
TC-025	CNTR MN CHASSIS	Engine Mount-Front	1	GTC-025
TC 026	CNTR MN CHASSIS	Engine Mount-Rear	1	GTC-026

TC 027	CNTR MN CHASSIS	Shock Mounts	4	GTC-027
TC 028	CNTR MN CHASSIS	Retaining Pin	1	GTC-028
TC 029	CNTR MN CHASSIS	Retaining Wire	1	GTC-029
TC 030	CNTR MN CHASSIS	Main Gr Axel	1	
TC 031	CNTR MN CHASSIS	Main Gr Axel Housing	1	
TC 032	CNTR MN CHASSIS	Main Gear Axel Tie	2	GTC-032
TC 033	CENTER SECTION	FLIGHT CONTROLS		GTC-033
TC 034	CNTR FLTR CNTRLS	Roll Lever-Long	1	GTC-034
TC 035	CNTR FLTR CNTRLS	Roll Lever-Short	1	GTC-035
TC 036	CNTR FLTR CNTRLS	Roll Lvr Pivot Blk	1	GTC-036
TC 037	CNTR FLTR CNTRLS	Roll Pivot Shaft	1	GTC-037
TC 038	CNTR FLTR CNTRLS	Pitch Lever	1	GTC-038
TC 039	CNTR FLTR CNTRLS	Pitch Relrnk Plate	2	GTC-039
TC 099	CNTR RADIO	Battery 6 Volt	2	GTC-099
TC 100	CNTR RADIO	Battery Box	1	GTC-100
TC 101	CNTR RADIO	Receiver Box	1	GTC-101
TC 102	CNTR RADIO	Servo Arm	2	GTC-102
TC 130	CENTER SECTION			
TC 102A	CNTR MN TRANS	MAIN TRANSMISSION		GTC-102
TC 103	CNTR MN TRANS	Front Pulley-60th	1	GTC-103
TC 104	CNTR MN TRANS	Rear Pulley-60th	1	GTC-104
TC 105	CNTR MN TRANS	Front Pulley-19-th	1	GTC-105
TC 106	CNTR MN TRANS	Belt	2	GTC-106
TC 107	CNTR MN TRANS	Pulley Shaft-Front	1	GTC-107
TC 108	CNTR MN TRANS	Pulley Shaft-Rear	1	GTC-108
TC 109	CNTR MN TRANS	Main Shaft	1	GTC-109
TC 110	CNTR MN TRANS	Main Shaft Washer	1	GTC-110
TC 111	CNTR MN TRANS	Tower Bearing Block	1	GTC-111
TC 112	CNTR MN TRANS	Top Channel	1	GTC-112
TC 113	CNTR MN TRANS	Bottom Channel	1	GTC-113
TC 114	CNTR MN TRANS	Front Bearing Block	1	GTC-114
TC 115	CNTR MN TRANS	Rear T/R Bearing Block	1	GTC-115
TC 116	CNTR MN TRANS	Rear Shft Brng Blk-Top	1	GTC-116
TC 117	CNTR MN TRANS	Rear Shft Brng Blk-Botm	1	GTC-117
TC 118	CNTR MN TRANS	Tail Drive Coupler	1	GTC-118
TC 119	CNTR MN TRANS	Stiffening Rod	1	GTC-119
TC 120	CNTR MN TRANS	Tail Intermediate Shaft	1	GTC-120
TC 121	CNTR MN TRANS	Tail Drive Pinion	1	GTC-121
TC 122	CNTR MN TRANS	Tail Drive Gear	1	GTC-122
TC 123	CNTR MN TRANS	Front Shaft Bearing	2	GTC-123
TC 124	CNTR MN TRANS	Rear Shaft Bearing	2	GTC-124
TC 125	CNTR MN TRANS	Intermediate Shaft Brng	2	GTC-125
TC 126	CNTR MN TRANS	Tower Block Bearing	1	GTC-126
TC 127	CNTR MN TRANS	Main Shaft Collar	1	GTC-127

TC 128	CNTR MN TRANS	Engine Shaft Bushing	1	GTC-128
TC-129	CNTR MN TRANS	Thrst Ndl Brng/2 1/10 Rac	1	GTC-129
TC 135	CNTR MN TRANS	Dblr Plate	1	GTC-135
TC 136	CNTR MN TRANS	Servo Mount	1	GTC-136
TE 001	POWER PLANT	ENGINE	1	GTE-001
TE 002	PWR PLNT-ENG	Air Filter	1	GTE-002
TE 003	PWR PLNT-ENG	Engine Shaft	1	GTE-003
TE 004	PWR PLNT-ENG	Cooling Fan	1	GTE-004
TE 005	PWR PLNT ENG	Centrifugal Clutch	1	GTE-005
TE 006	PWR PLNT-ENG	Clutch Bell w/Pul & Brng	1	GTE-006
TE 007	PWR PLNT-ENG	Starter	1	GTE-007
TE 008	PWR PLNT-ENG	Starter Pinion	1	GTE-008
TE 009	PWR PLNT-ENG	Engine Sprocket	1	GTE-009
TE 010	PWR PLNT-ENG	One-way Sprague Clutch	1	GTE-010
TE-011	PWR PLNT-ENG	#35 Chain	1	GTE-011
TE 012	PWR PLNT ENG	Starter Mounting Block	1	GTE 012
TE-013	PWR PLNT-ENG	Compression Release Brkt	2	GTE-013
T 100	POWER PLANT	HIRD-D COMPLETE		GT-100
TE-014	PWR PLNT ENG	Sprague Clutch Adapter	1	GTE-014
TE 015	PWR PLNT-ENG	Starter Mount Brkt	1	GTE-015
TE 016	PWR PLNT-ENG	Shield Clutch	1	GTE-016
TE 017	PWR PLNT-ENG	Adapter Input Shaft	1	GTE-017
TE 018	PWR PLNT-ENG	"O" Clip for 3/4" Shaft	2	GTE-018
TE 019	PWR PLNT-ENG	Pivot Bolt w/ Link	1	GTE-019
TE 020	PWR PLNT-ENG	Ball Link	1	GTE-020
TE 021	PWR PLNT-ENG	Spacing Washers	4	GTE-021
TE 022	PWR PLNT ENG	Spacing Washers	5	GTE-022
TE 023	PWR PLNT ENG	Exhaust Pipe	2	GTE-023
TE 024	PWR PLNT ENG	Fan Doubler Plate (A)	1	GTE-024
TE 025	PWR PLNT ENG	Fan Doubler Plate (B)	1	GTE-025
TE 026	PWR PLNT-ENG	Exhaust Header	2	GTE-026
TE 027	PWR PLNT-ENG	Bearing-Clutch Bell	1	GTE-027
TE 028	PWR PLNT ENG	Adapter-Output Shaft	1	GTE-028
TE 029	PWR PLNT-ENG	Pivot Bolt	1	GTE-029
TE 030	PWR PLNT ENG	Inlet Venturi	1	GTE-030
TT 001	TAIL SECTION	TAIL GEARBOX		GTT-001
TT 002	TAIL TL GRBX	Coupler	1	GTT-002
TT 003	TAIL TL GRBX	Input Shaft	1	GTT-003
TT 004	TAIL TL GRBX	Output Shaft	1	GTT-004
TT 005	TAIL TL GRBX	Front Case (Input)	1	GTT-005
TT 008	TAIL TL GRBX	Rear Case (Output)	1	GTT-008
TT 007	TAIL TL GRBX	Mounting Plate	1	GTT-007

GMP PARTS INVENTORY

TT 008	TAIL TL GRBX	Bearing	4	GTT-008
TT 009	TAIL TL GRBX	Input Gear	1	GTT-009
TT 010	TAIL TL GRBX	Output Gear	1	GTT-010
TT 011	TAIL TL GRBX	Output Shaft Collar	1	GTT-011
TT 012	TAIL TL GRBX	Pitch Plate Shaft	1	GTT-012
TT 013	TAIL TL GRBX	Bearing Collar	1	GTT-013
TT 014	TAIL TL GRBX	Pitch Plate Spacer	1	GTT-014
TT 015	TAIL TL GRBX	Pitch Plate	1	GTT-015
TT 016	TAIL TL GRBX	Pivot Bolt	4	GTT-016
TT 017A	TAIL TL GRBX	T/R Drive Adapter	1	GTT-017
TT 018	TAIL TL GRBX	3 blade T/R Unit	1	GTT-018
TT 019	TAIL TL GRBX	Pitch Control Arm	1	GTT-019
TT 020	TAIL TL GRBX	Control Arm Mntg Plate	1	GTT-020
TT 021	TAIL TL GRBX	Control Arm Bushing	1	GTT-021
TT 022	TAIL TL GRBX	Tail Blades	3	GTT-022
TT 023	TAIL TL GRBX	Gearbox Cover	1	GTT-023
TT 024	TAIL TL GRBX	Pitch Plate Brng	1	GTT-024
TT 025	TAIL TL GRBX	Anti-Rotation Block	3	GTT-025
TT 026	TAIL TL GRBX	Bearing-Pitch Arm	2	GTT-026
TT 030	TAIL SECTION	REAR FUSELAGE		GTT-030
TT 031	TAIL REAR FUS	F/G Tail Boom	1	GTT-031
TT 032	TAIL REAR FUS	Front Former	1	GTT-032
TT 033	TAIL REAR FUS	Center Former	1	GTT-033
TT 034	TAIL REAR FUS	Rear Former	1	GTT-034
TT 035	TAIL REAR FUS	T/R Mounting Block	1	GTT-035
TT 036	TAIL REAR FUS	Rear Filler Former	1	GTT-036
TT 037	TAIL REAR FUS	Brass Drive Tube	1	GTT-037
TT 038	TAIL-REAR FUS	Flex Shaft	1	GTT-038
TT 039	TAIL-REAR FUS	Drive Tube Mount	1	GTT-039
TT-040	TAIL-REAR FUS	Drive Tube Support	1	GTT-040
TT 042	TAIL REAR FUS	Servo Extension	1	GTT-042
TT 043	TAIL REAR FUS	Reinforcement Bracket	2	GTT-043
TT-044	TAIL-REAR FUS	Drive Tube Mount-Rear	1	GTT-044
TT 045	TAIL-REAR FUS	Doubler Piece	4	GTT-045
TT 046	TAIL-REAR FUS	Servo mount	1	GTT-046
TT-047	TAIL-REAR FUS	Winglets	2	GTT-047
TT 048	TAIL-REAR FUS	Stabilizers	2	GTT-048
TT 049	TAIL REAR FUS	Mt. Bracket-Winglet	2	GTT-049
TT-050	TAIL-REAR FUS	Spar Stabilizer	1	GTT-050
TR 001	ROTOR HEAD	ROTOR HEAD		GTR-001
TR 002	ROTOR HEAD	Hub	1	GTR-002
TR 003	ROTOR HEAD	Yoke Side Plate	2	GTR-003
TR 004	ROTOR HEAD	Blade Holder	2	GTR-004
TR 005	ROTOR HEAD	Blade Holder housing	2	GTR-005

TR 027	ROTOR HEAD	Seesaw Teter Bearing	2	GTR-027
TR 028	ROTOR HEAD	Pivot Pin Bearing	2	GTR-028
TR 029	ROTOR HEAD	Thrust Brng w/2 Races 1/1	2	GTR-029
TR 030	ROTOR HEAD	Pushrod Guide	2	GTR-030
TR 031	ROTOR HEAD	Damper Adjusting Screw	2	GTR-031
TR-032	ROTOR HEAD	Damper Adjusting Housing	2	GTR-032
TR 033	ROTOR HEAD	Blade Doubler	2	GTR-033
TR 034	ROTOR HEAD			
TR 035	ROTOR HEAD	Seesaw Mixing Arm Brng	4	GTR-035
TR 036	ROTOR HEAD	Yoke Side Plt Pvt Brng	2	GTR-036
TR-037	ROTOR HEAD	Bushing, Main Blade	2	GTR-037
TR 038	ROTOR HEAD	Yoke Pivot Pin	1	GTR-038
TR 039	ROTOR HEAD	Seesaw Teeter Pin	1	GTR 039
TR 040	ROTOR HEAD	Yoke Damper Pin	1	GTR-040
TR 041	ROTOR HEAD	Washout Hub	1	GTR-041
TR 042	ROTOR HEAD	Scissor Arm	2	GTR-042
TR 043	ROTOR HEAD	Connecting Rod Block	2	GTR-043
TR 044	ROTOR HEAD	Spacer-Lead/Lag Plt	8	GTR-044
TS 001	SUNDRIES	SUNDRIES		GTS-001
TS 002	SUNDRIES	Fuel Tank	1	GTS-002
TS 003	SUNDRIES	Fuel Line	2	GTS-003
TS 004	SUNDRIES	Fuel Tank Fitting	1	GTS-004
TS 005	SUNDRIES	Wheel-6"	2	GTS-005
TR 006B	ROTOR HEAD	Seesaw Hub	1	GTR-006B
TR 007	ROTOR HEAD	Mixing Arm	4	GTR-007
TR 008	ROTOR HEAD	Ball Joint-Right	6	GTR-008
TR 010	ROTOR HEAD	Seesaw Bearing Block	2	GTR-010
TR 011A	ROTOR HEAD	Seesaw Sideplates	2	GTR-011A
TR 012	ROTOR HEAD	Flybar Mounting Block	2	GTR-012
TR 013	ROTOR HEAD	Blade Holder Spacer	2	GTR-013
TR 014	ROTOR HEAD	Pivot Bearing Housing	2	GTR-014
TR 015	ROTOR HEAD	Blade Holder Bush	2	GTR-015
TR 016A	ROTOR HEAD	Lead/Lag Plate-Top	2	GTR-016A
TR 017A	ROTOR HEAD	Lead/Lag Plate-Btm	2	GTR-017A
TR 018	ROTOR HEAD	Blade Arm	2	GTR-018
TR 019	ROTOR HEAD	Pivot Bolt Block	2	GTR-019
TR 020A	ROTOR HEAD	Lead/Lag Standoff	2	GTR-020A
TR 021	ROTOR HEAD	Flybar	2	GTR-021
TR 022	ROTOR HEAD	Pushrod	2	GTR-022
TR 023	ROTOR HEAD	Flybar Weights	2	GTR-023
TR 025B	ROTOR HEAD	Main Rotor Blades (Set)	2	GTR-025
TR 026A	ROTOR HEAD	Blade Holder Bearing	4	GTR-026A
TR 026B	ROTOR HEAD	Blade Holder Inner Race	4	GTR-026B
TR 026C	ROTOR HEAD	Blade Axle Bolt Bushing	2	GTR-026C

GMP PARTS INVENTORY

TS 006	SUNDRIES	Wheel-4"	2	GTS-006
TS 007	SUNDRIES	Mag Switch	1	GTS-007
TS 008	SUNDRIES	Main Servo Switch	1	GTS-008
TS 009	SUNDRIES	Pin Receptacle	1	GTS-009
TS 010	SUNDRIES	Socket Plug	1	GTS-010
TS 012	SUNDRIES	Hose Clamp-1/2"	4	GTS-012
TS 013	SUNDRIES	Fuel Tank Mount	2	GTS-013

MAIN CHASSIS HARDWARE

List of Area Suppliers

Company	Items	Location	Phone Number
Ben Franklin	Spackle Knife	Monterey, Ca	(408)646-5141
Big 5 Sptg Goods	Nose Weights	Monterey, Ca	(408)372-3284
Coast Hardware	Tools	Pacific Grove, Ca	(408)372-3284
Grand Auto	Fuel Storage Can	Seaside, Ca	(408)394-1472
Grove Auto Parts	E. P. Grease	Pacific Grove, Ca	(408)649-5385
Hamltn Gdn& Pwr	2-Cycle Oil	Seaside, Ca	(408)394-1622
H&H Hardware	Sandpaper/Bolts	Seaside, Ca	(408)899-2451
Kragen Auto Wrks	Exhaust/Fuel Line	Seaside, Ca	(408)394-7515
Lacey Automotive	Lubricants	Seaside, Ca	(408)394-1418
Mr. Metric	Metric Tools/Hdwr	San Jose, Ca	(408)286-8816
Orchard Supply	Hardware/Tools	Sand City, Ca	(408)899-5144
Pec's Hobbies	Helicopter Fuel	Mtnview, Ca	(415)968-0800
Penin. Car Color	Pinhole Sealant	Seaside, Ca	(408)394-2074
P.G. Bldrs Supply	Hardware	Pacific Grove, Ca	(408)373-4708
Sears	3/8" Drive Hexes	Salinas, Ca	(408)443-7094
Sheldon Hobbies	Aileron Chords	San Jose, Ca	(408)943-0872
Sports Ctr Bikes	Starter Chain Lube	Seaside, Ca	(408)899-2401
Sterling Instrument	Bearings/Cplings	New Hyde Pk, NY	(516)328-3300
Unocal 76	92 Octane Fuel	Monterey, Ca	N/A
Valley Fabrication	Custom Shims	Salinas, Ca	(408)757-5151

APPENDIX B: ENGINE REMOVAL AND INSTALLATION PROCEDURES

The following is a detailed description of the easiest and quickest procedure for the removal of the engine from the helicopter. Preceding the procedures, a detailed list of tools required has been provided.

<u>TOOLS REQUIRED</u>

1.) Metric hex wrench set, 1-10 millimeter sizes.(ball ended preferred)

2.) Double ended, small (6 inches long) crescent wrench.

3.) Large (10 inches or greater in length), straight head screwdriver.

4.) 3/8 inch drive metric and standard socket sets with small (approximately 6") and standard ratchets.

5.) Blue thread lock compound.

6.) Standard hex wrench set, 1/8'-3/4' sizes.

7.) Standard size crescent wrench.

8.) Standard and metric combination wrenches (1/4"-1" standard sizes, 8-15mm metric sizes)

9.) Short (approximately 2 inch long) large-bladed straight head screwdriver.

10.) Needle nose pliers

11.) Large welding C-clamp.

12.) Come along (block and tackle).

13.) Nylon strap.

Engine Removal Procedures

1. **Remove Forward Fuselage**

   A. Using a 10 inch long or longer straight head screwdriver, unfasten the six dzus fasteners on the forward fuselage.

   B. Spreading the fuselage laterally to avoid contact with the main rotor scissor assembly and carburetor, slide fuselage forward and remove it from the chassis.

2. **Remove Tail Pylon (two people recommended)**

   A. Unplug tail rotor control cord through the access port underneath tailboom.

   B. Using a 17 mm, 3/8" drive socket with the small (approx. 6" long) ratchet, remove the four tailboom attachment nuts and lock washers. For best results, remove the 2 bottom nuts first, followed by the two top nuts. (The second person supports the tailboom during this and the following step.)

   C. Slide tailboom aft and remove.

3. **Remove Main Rotor Blade Lead-lag Links**

   A. Using a 3/8" box ended combination wrench and a 1/8" hex wrench, remove both end-bolts for each lead-lag link and remove the two links. (one per blade)

4. **Remove Main Rotor Blades (two people recommended)**

   A. Using an 8 mm hex wrench and the standard sized crescent wrench, loosen and remove the main rotor blade attachment bolt. The second person supports the blade during this step.

   B. With the bolt removed, slide the rotor blade from its sleeve and remove.

   C. Repeat steps A and B for the second rotor blade

5. **Remove Hiller Paddles**

A. Using the box end of a 7/16" combination wrench, loosen and remove the locknuts from the ends of the two Bell-Hiller paddles.

B. Using a 2 mm hex wrench, loosen the two set screws holding each paddle arm.

C. Remove Bell-Hiller stabilization paddles from the main rotor head assembly.

6. Disassemble Nose/Electronics Compartment

A. Drain the fuel tank using a hand pump and disconnect the two fuel lines from the carburetor.

B. Disconnect and remove the 12 volt and 4.8 volt batteries.

C. Using the standard sized crescent wrench, loosen and remove the through bolt for the nose ballast weights and remove the weights.

7. Assemble the Maintenance Platform and Mount the Chassis (two people recommended)

A. Obtain the Allison engine test stand depicted in Figure 37, Chapter VI. (Property of Professor G. Hobson)

B. Using the standard 3/8" socket and ratchet and the standard crescent wrench, attach the two wooden chassis support assemblies depicted in Figure 41 to the test stand as depicted in Figure 12, Chapter III.

C. Using two people, lift and invert the helicopter chassis by gripping it at the bends in the skid supports and place it on the maintenance platform. Cutaways in the chassis supports allow clearance for the main rotor servo housing. (See Figure 12, Chapter III)

8. Disconnect All Accessories Attached to the Engine

A. Using a short (approx.. 2" long) straight head screwdriver, loosen the exhaust tube clamp and pull the exhaust tube free from the exhaust manifold.

B. Using a 5 mm hex wrench, remove the four exhaust manifold attachment screws and remove the exhaust manifold through the side access port.

C. Using the small double ended crescent wrench and a 5/32" hex wrench, remove the four bolts (oriented vertically) connecting the upper engine mount cross member to its wall-mounted supports.

D. Remove the two cylinder head screws that connect the upper engine mount cross member to the aft cylinder head with a 5 mm hex wrench.

E. Remove the master link from the starter chain using needle nose pliers or a master link C-clamp spreader and remove the chain.

F. Disconnect the throttle and choke linkages (arms) their respective drive motors. The plastic cups pop off the ball-ended drive pins on the electric motors.

G. Using a 10 mm open ended combination wrench and the small double ended crescent wrench, remove the two vertically oriented bolts connecting the carburetor and air intake nozzle assembly to the engine neck and remove the carburetor assembly through the side access port.

H. Using a 10 mm, 3/8" drive socket with the small ratchet, and a 5 mm hex wrench, remove the starter upper attachment bolt.

I. Using a 5 mm hex wrench and the small double ended crescent wrench, loosen the two starter lower cinch bolts. Support starter from underneath to prevent it from dropping into the engine compartment while the bolts are loosened. Lower starter and remove it through the side access port.

9. Engine Removal

A. Attach a welding C-clamp to an overhead I-beam.

B. Obtain a come-along and hook one end to the C-clamp. (property of Model Maker Don Harvey)

C. Obtain nylon strap to act as a harness . (Bldg. 214 forklift has some)

D. As depicted in Figure 21, Chapter IV, sling the strap under the engine starter sprocket on two sides of the shaft and hook both ends to the lower hooked end of the come-along.

E. Center the engine beneath the C-clamp and remove any slack in the chain using the come-along.

F. Using the standard crescent wrench and a 8 mm hex wrench, remove the four lower engine mount attachment bolts.

G. Using the come-along, slowly raise the engine, angling the engine as necessary to ensure carburetor neck and cylinder head clearance through the bottom access port.

H. Inspect the engine output shaft above the clutch and the main transmission area for the three spacer shims used between the clutch and the transmission.

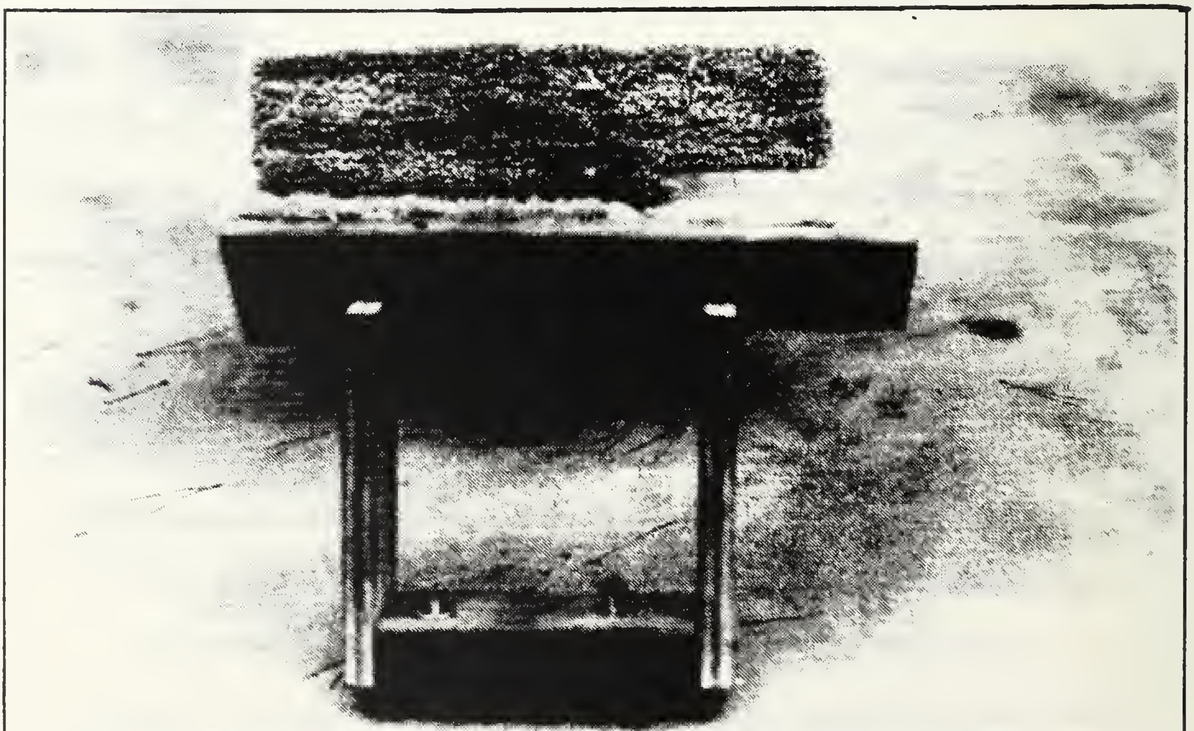


Figure 41. Wooden Chassis Supports for Maintenance Stand

APPENDIX C: WESTLAKE ENGINE OPERATOR'S MANUAL

4.2 GENERAL DATA - SERIES 2100D ENGINE

Weight	Ranges from 8.0 kg (17.5 lbs) to 10.4 kg (23 lbs) Depending on configuration See appropriate Inst. Drawing
Dimensions	(See Installation Drawing)
Bore	66 mm (2.59 in)
Stroke	50 mm (1.96 in)
Cubic capacity	342 cc (20.9 cu.in)
Compression ratio	7.1 (effective)
Compression pressure (cold)	930-965 kPa (135-140 psig)
Power at rated speed	25 bhp (18,64 kw) to SAEJ 607(a)
Maximum speed rated	7000 rev/min
Idle speed	1500-3000 rev/min (Depending on propeller)
Maximum torque	32.50 Nm (24 lbf.ft) at 4000 rev/min
Carburettor	Mikuni BN-34-30 Diaphragm Type

CAUTION:

CHANGES IN EXHAUST SYSTEMS AND/OR AIR CLEANERS WILL REQUIRE RE-ADJUSTMENT OF CARBURETTOR NEEDLE JETS.

Fuel Consumption.................. Approx. 5.6 litres/hour @ 5250 rev/min Against propeller load

Type of Fuel.......................... gasoline/oil 4% (25:1)

Gasoline.............................. RON 92 octane minimum

CAUTION:

LEAD-FREE GASOLINE
MUST NOT BE USED

Oil.. Finamix 2-stroke or Silkolene Comp 2 Pre-mix

CAUTION;

MULTIGRADE OIL
MUST NOT BE USED

Fuel pipe............................. 6,0 mm i.d. (0.25 in) (not supplied) to SAE J30d

Airgap between electronic module and flywheel........................ 0,46 to 0,51 mm (0.018 to 0.020 in)

Spark Plug

Standard Cylinder head....... Bosch WSR 6F (9.5 mm reach)

Large Cylinder head........... Bosch W6 BC (12.7 mm reach)

Spark Plug Gap

Bosch WSR 6F........................... 0,50 to 0.56 mm (0,020 to 0,022 in)

Bosch W6 BC................................ 0,7 to 0,8 mm
(0.028 to 0.031 in)

Cylinder head temperature (maximum).............. 250 deg C
(Measured at spark plug gasket) (482 deg F)

Exhaust gas temperature (maximum)............... 550 deg C
(Measured 25-30 mm from exhaust flange) (1022 deg F)

Spark plug torque setting......................... 29,80 Nm
(22 lbf.ft)

CAUTION:

SPARK PLUG GASKET MUST BE REMOVED IF A CYLINDER HEAD TEMPERATURE THERMOCOUPLE IS USED.

Cylinder head screws.................... 12.2 Nm (108 lbf.in)
torque setting. NOTE: RE-TORQUE CYLINDER HEAD SCREWS AFTER INITIAL 2 HOURS RUNNING.

Cylinder base screws.................... 12.2 Nm (108 lbf.in)
torque setting

CAUTION:

TORQUE WRENCH MUST BY USED TO ENSURE CORRECT TORQUE SETTING

NOTE: ALL TORQUE CHECKS MUST BE CARRIED OUT WITH THE ENGINE COLD.

5.0 INSTALLATION

WARNING:

BEFORE OPERATING, ENGINE MUST BE SECURED TO MOUNTING BRACKET OR AIRFRAME. FAILURE TO SECURE ENGINE CORRECTLY MAY RESULT IN DAMAGE TO AIRFRAME AND/OR LOSS OF ENGINE AND INJURY TO OPERATOR.

CAUTION:

ALWAYS ENSURE IGNITION IS SWITCHED OFF (GROUNDED), WHEN ROTATING ENGINE CRANKSHAFT WITH SPARK PLUGS REMOVED FROM CYLINDERS, OTHERWISE DAMAGE TO IGNITION SYSTEM WILL OCCUR.

5.1 Remove all protective coverings.

5.2 Remove keeper-plate from ignition flywheel.

5.3 Fit recommended air inlet horn and/or air filter suitable for the installation. (See Installation Drawing).

WARNING:

THE MOUNTING BRACKET MUST BE OF A DESIGN THAT WILL NOT FAIL UNDER NORMAL RUNNING CONDITIONS.

5.4 Fit engine to engine mounting bracket on airframe (refer to Installation Drawing).

<u>Base Mounting</u> 4 x M8 screws with suitable fastener locking device, minimum thread engagement 15 mm. Torque screws to 14 Nm (124 lbf ins) maximum.

<u>Rear Mounting</u> 6 x M6 screws with suitable fastener locking device, minimum thread engagement 10 mm. Torque screws to 8 Nm (72 lbf ins) maximum.

5.5 Fit 73 mm stub exhaust pipes or installation exhaust system, using gaskets supplied (refer to Installation Drawing) and torque tighten bolts to 6 Nm (53 lbf ins) maximum.

5.6 Connect fuel line (customer supply) to carburettor fuel connector (FIGURE 5-1). Ensure a fuel filter 50 microns (0.002 in) is incorporated in fuel line.

5.7 Connect throttle cable (customer supply) to carburettor throttle lever (FIGURE 5-1).

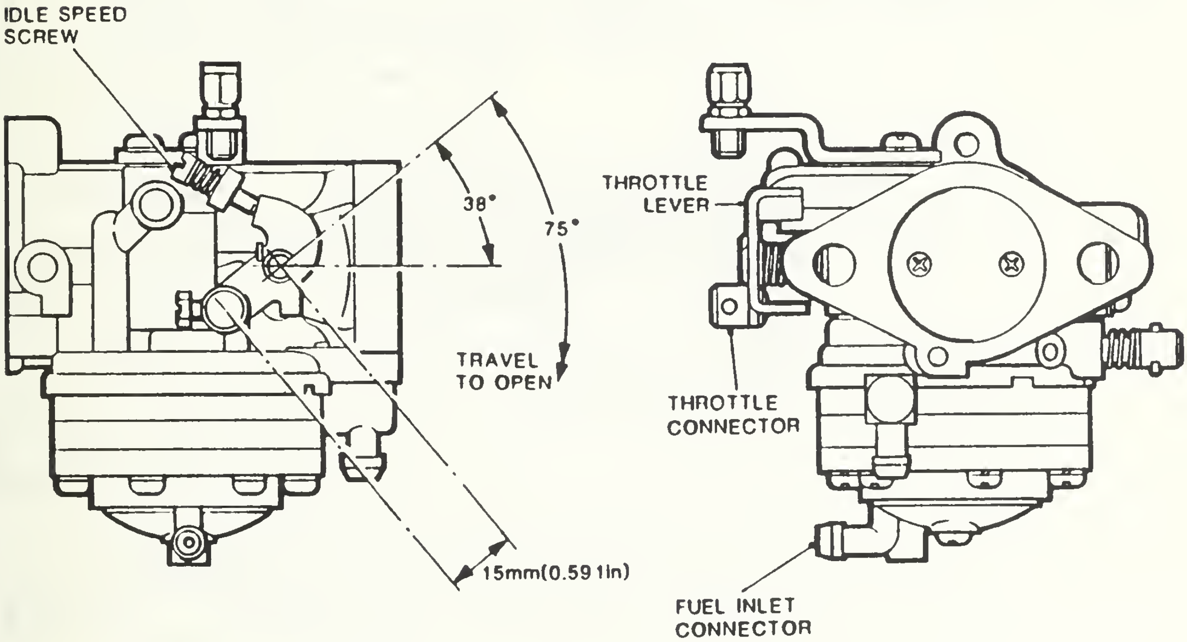


FIGURE 5-1 : CARBURETTOR

5.8 Connect ignition cut-out wire to ignition switch (customer supply) (reference FIGURE 5-2).

5.9 Remove protection caps from spark plug holes and rotate engine crankshaft 4 - 5 times to clear excess oil from the engine. Check and gap, new spark plugs and install. Torque to 29.80 Nm (22 lbf ft).

NOTE: Spark plug gap, see general data.

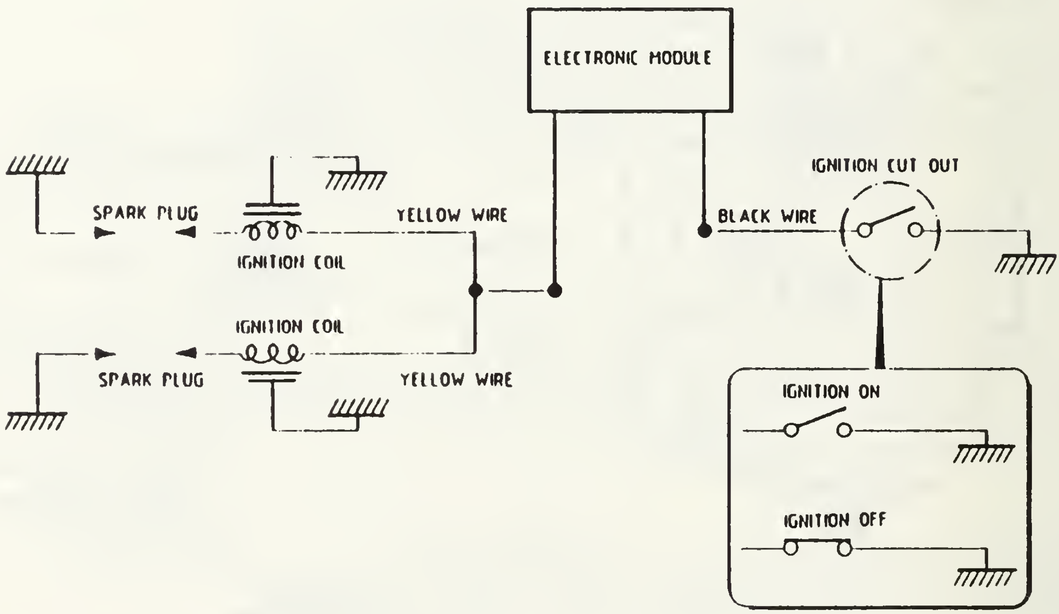


FIGURE 5-2 : IGNITION SYSTEM - CIRCUIT DIAGRAM

WARNING:

MAKE SURE ALL ROTATING PARTS ARE FREE OF OBSTRUCTIONS BEFORE STARTING THE ENGINE

5.10 Start engine and set carburettor to give an engine idle speed of 2400 rev/min or as required. (See adjustments and maintenance for setting of carburettor).

CAUTION:

ENGINE MUST BE UNDER NORMAL OPERATING LOAD (PROPELLER INSTALLED) BEFORE ENGINE IS STARTED.

6.0 OPERATION

WARNING:

> DO NOT FILL FUEL TANK TO MAXIMUM CAPACITY. COOL GASOLINE EXPANDS CONSIDERABLY, DUE TO HIGHER OUTSIDE TEMPERATURES, AND BUILDS UP PRESSURE IN FUEL TANK. THIS CAN CAUSE FUEL LEAKAGE AND A POTENTIAL FIRE HAZARD. ENSURE FUEL TANK IS PROPERLY VENTED.

6.1 Recommended Gasoline

Use only leaded automotive gasoline that has a minimum octane rating of 92 RON.

If recommended gasoline is not available, contact the engine manufacturer.

CAUTION:

> DO NOT USE UNLEADED GASOLINE.

WARNING:

> GASOLINE IS EXTREMELY FLAMMABLE AND HIGHLY EXPLOSIVE UNDER CERTAIN CONDITIONS. ALWAYS STOP ENGINE AND DO NOT SMOKE OR ALLOW NAKED FLAMES OR SPARK NEAR WHEN REFUELLING. ALWAYS MIX IN WELL-VENTILATED AREAS.

6.2 Recommended Lubricant

Use only (Petrofina) Finamix 2-stroke oil or Bel-Ray MC-1+. If recommended 2-stroke oil is not available, contact the engine manufacturer.

CAUTION:

> DO NOT UNDER ANY CIRCUMSTANCES USE MULTIGRADE OILS.

6.3 Fuel Mixture

The correct fuel mixture is 1 part of oil to 25 parts of gasoline (4% oil mixture).

Metric Measure	U.S. Measure	Imperial Measure
160 cc oil to each 4 litres of gasoline	5 fluid oz oil to each 1 U.S. gallon of gasoline	6 fluid oz oil to each 1 Imp gallon of gasoline

USE AT 25:1 RATIO, AS SHOWN ABOVE

IMPORTANT:

USING LESS THAN THE RECOMMENDED PROPORTION OF OIL MAY RESULT IN SERIOUS ENGINE DAMAGE FOR LACK OF SUFFICIENT LUBRICATION. USING MORE THAN THE RECOMMENDATIONS COULD CAUSE SPARK PLUG FOULING, ERRATIC CARBURATION,EXCESSIVE SMOKING AND FASTER-THAN-NORMAL CARBON ACCUMULATION.

CAUTION:

GASOLINE IS EXTREMELY FLAMMABLE AND HIGHLY EXPLOSIVE UNDER CERTAIN CONDITIONS. OBSERVE FIRE PREVENTION RULES, PARTICULARLY THE MATTER OF SMOKING. MIX FUEL OUTDOORS OR AT LEAST IN A WELL VENTILATED LOCATION.

Use only clean oil and gasoline containers as even a very small particle of dirt can cause carburation problems.

Mix fuel accurately in a remote tank. To ensure thorough mixing of oil and gasoline, fill container with gasoline to one quarter full, add oil and then add balance of gasoline. Mix thoroughly before using.

NOTE: Always use fresh gasoline.

6.4 Starting

WARNING:

MAKE SURE ALL ROTATING PARTS ARE FREE OF OBSTRUCTIONS BEFORE STARTING ENGINE.

CAUTION:

THE ENGINE IS AIRCOOLED AND MUST NOT BE RUN IN STATIC CONDITIONS UNLESS AN ADEQUATE COOLING AIR-FLOW IS SUPPLIED.

6.4.1 Check that spark plug leads are securely connected to spark plug terminals.

6.4.2 Turn on fuel supply.

6.4.3 Set decompressors by depressing caps situated on cylinder barrels (FIGURE 6-1).

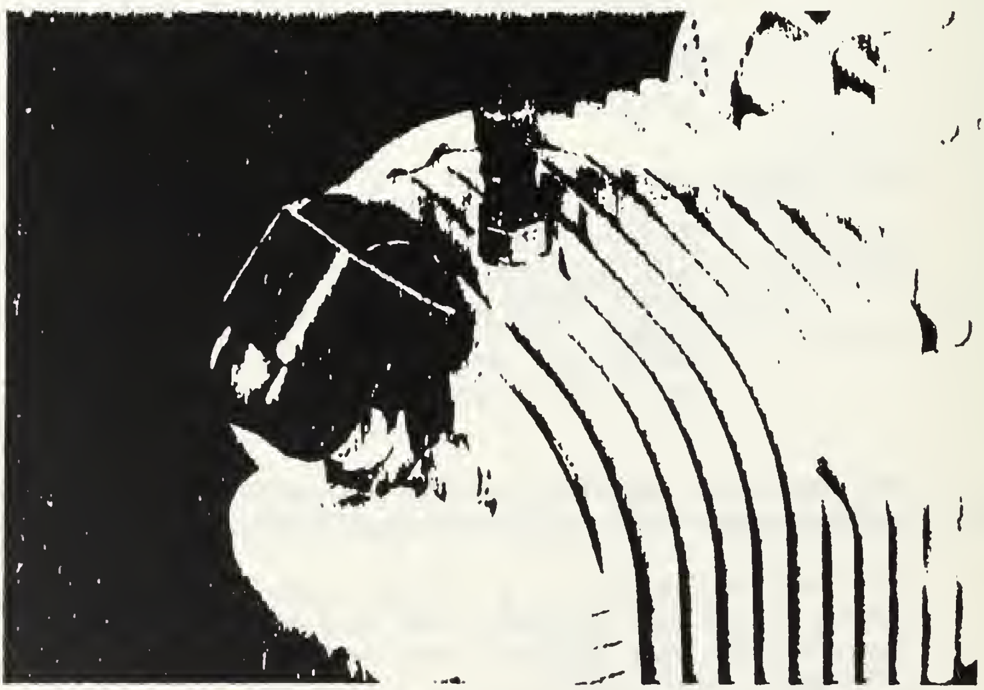


FIGURE 6-1

6.4.5 On a cold engine (first start), move throttle control to approximately half-open position.

NOTE: With the engine warm, it can be started at idle position.

6.4.6 Turn the ignition switch to ON position.

6.4.7 Crank engine until engine fires and continues to run.

NOTE: A minimum starting speed of 1,000 rev/min is required.

6.4.8 Move throttle control to 'idle' position.

NOTE: Decompressors must be depressed each time engine fires, but fails to start.

6.5 Stopping

6.5.1 Move throttle control to 'idle' position.

6.5.2 Turn ignition switch to OFF position.

WARNING:

DISCONNECT SPARK PLUG LEADS BEFORE WORKING ON ANY PART OF ENGINE OR ACCESSORIES.

6.6 Break-in (New engine)

CAUTION:

FOLLOW BREAK-IN PROCEDURE CAREFULLY.

During the first 60 minutes, operate the engine for short periods of time at varying speeds up to three-quarters-open throttle. Avoid operating at low and continuous speeds to prevent build-up of heat. After this period use the engine as required without exceeding the specified maximum temperatures.

NOTE: RE-TORQUE CYLINDER HEAD SCREWS AFTER INITIAL 2 HOURS RUNNING.

NOTE: During break-in 10cc of "Molyslip E" per 5 litres of gasoline may be used to improve lubrication and protect the engine. Continued use of Molyslip E in the quantities specified will not adversely affect the engine and may prolong its useful life.

7.0 INSPECTION AND SERVICE

Check the following items before each period of operation.

7.1 Fuel

Before starting the engine, be sure that there is an adequate amount of fuel in the tank. The fuel ratio must be 25:1 mixture of gasoline and oil.

CAUTION:

> DO NOT FILL FUEL TANK COMPLETELY FULL. GASOLINE WILL EXPAND AS IT WARMS, CAUSING LEAKAGE AND A FIRE HAZARD IF THERE IS NOT ROOM FOR EXPANSION.

7.2 Fuel Line Connections

Check fuel line connections from fuel tank to engine for leaks. Make sure fuel line is firmly connected.

7.3 Spark Plugs

Keep spark plugs clean; a fouled plug can be the cause of serious engine problems. Make sure spark plug connections are tight.

Do not sand-blast, scrape or otherwise attempt to service spark plugs that are in a poor condition - best engine results are obtained with new spark plugs.

7.4 Cooling

Make sure baffles and cooling shrouds (if fitted) are in place and secure. Check that air intake openings are clean and unrestricted. Ensure cooling fins on the engine are clean and not damaged or broken.

WARNING:

> DO NOT OPERATE ENGINE WITH DAMAGED OR BROKEN COOLING FINS.

8.0 ADJUSTMENTS AND MAINTENANCE

WARNING:

> MAKE SURE IGNITION SWITCH IS IN OFF POSITION AND SPARK PLUGS LEADS ARE DISCONNECTED BEFORE WORKING ON ANY PART OF THE ENGINE OR ANCILLARY EQUIPMENT.

8.1 Spark Plugs

Replace spark plugs every 25 running hours or as required.

Remove spark plugs and check condition; replace if carbon fouled or if porcelain is cracked. The colour of the spark plug is a good indication of operating conditions. Take corrective action if other than normal operation is indicated. Refer to spark condition chart below:

BLACK	TAN	WHITE
CARBON FOULING	NORMAL	OVERHEATING

When installing spark plug, set plug gap (see general data) and clean the spark plug seat in the cylinder head. Install plug and gasket and torque tighten to 29,80 Nm (22 lbf ft.).

8.2 Carburettor Adjustments

WARNING:

> WHEN ADJUSTMENT IS MADE WITH ENGINE RUNNING, BE EXTREMELY CAREFUL NOT TO TOUCH MOVING PARTS AND HOT AREAS.

The tendency for the engine to "4 stroke" can be reduced by a slightly lean mixture. A low idle speed will impair engine acceleration or throttle response when the throttle is opened rapidly.

The engine is air cooled and must not be run in static conditions unless an adequate cooling airflow is supplied to keep the cylinder head temperature within the specified limit (see general data).

WARNING:

AFTER SERVICING, MAKE SURE ALL SAFETY GUARDS ARE REPLACED AND SECURED.

The initial carburettor "Hi" and "Lo" needle jets and the idle-stop screw are adjusted at the factory, if further adjustment is required due to installation and/or geographical location, then:

- Screw idle-speed screw in or out to obtain required idle speed.

- The low-speed needle jet should be adjusted to obtain a smooth idle.

The carburettor will require repeated re-adjustments between the idle-speed screw and the low-speed needle jet, until a smooth idle is obtained at the required idle speed.

NOTE: Clockwise adjustment of the adjusting screws decreases the amount of fuel/oil mixture delivered and vice-versa.

8.3 Factors that can affect carburation

In some instances, carburation which has been properly set up in particular conditions, can then be upset by certain factors, i.e.:

change of fuel used

change in atmospheric pressure

change in air temperature

change in exhaust systems.

If in any doubt, contact engine manufacturer.

8.3.1 Check initially to see how easy the engine responds to the throttle when opened smoothly and fully. A certain amount of sluggishness is an indication of a lean mixture and it is necessary to quickly open the high-speed screw until the engine begins to "4 stroke". Again, open the throttle smoothly until it is fully open, while watching the rpms obtained. Continue this evaluation by slightly 'leaning' the high-speed mixture each time the throttle response is checked and the rpms read. This is continued until the mixture needs to be richened in order to obtain the highest possible rpms with the propeller installed.

The best initial choice is where the carburation is the richest possible but without an rpm drop.

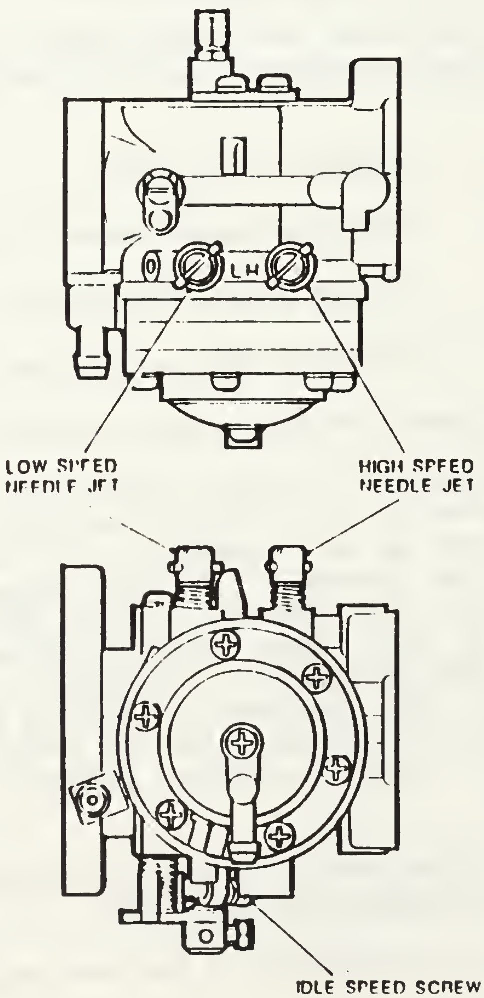
Following the running-in of the new engine a readjustment will be required.

If rich, the "4 stroking" will be pronounced and the engine will accelerate quickly up to a point - after which the rpm will not increase. A good rule is to have the idle mixture slightly rich, in order to avoid the possibility of having the engine stop, and to allow better throttle response.

NOTE: All adjustments must be made with the air filter and/or inlet horn installed. If adjustments are made with the filter and/or inlet horn removed, the carburation will be incorrect when the filter and/or inlet horn is reinstalled.

Adjustment of the high-speed needle jet must be done while monitoring the spark plug gasket temperatures and the engine speed. The high-speed adjustment is made with a hot engine, once the idle adjustments have been satisfactorily completed.

The engine should be fully warmed up before any adjustment is made to the carburettor.



NOTE: While optimising the carburation, it is necessary that the engine holds maximum rpm for a few seconds during each tachometer reading. For this reason a slightly rich mixture can prevent the risk of engine seizure, which can happen to new engines running lean.

8.3.2 Change in atmospheric pressure and in air temperature

Variations in pressure or temperature cause a change in the air density and consequently a change in the fuel/air ratio and further tuning may therefore become necessary.

A decrease in atmospheric pressure, with consequent decrease in air density, causes a mixture enrichment and smaller needle jet openings will therefore be required.

Altitude variations also produce changes in the carburation and they too cause changes in the air density. Prolonged use of an engine at an altitude higher than 1500 metres (5000 ft approx), for which the carburation was originally set up for operation at around sea level, would require a change of needle jet settings in proportion to the pressure change.

In this case too, a decrease in pressure should be compensated by a reduction of the needle jet openings.

Furthermore, a lowering of air temperature produces an increase in air density and consequently a mixture weakening; therefore an increase in the needle jet openings is required.

Summarising, it can be said that any decrease in air pressure, increase in altitude or in air temperature should be compensated for by a decrease in the needle jet openings.

Conversely, any increase in pressure or decrease in altitude or in temperature should be compensated by an increase in the needle jet openings.

8.3.3 Changes in exhaust system

The carburettor supplied is calibrated to suit a stub pipe exhaust system 73 mm long, if any other exhaust system is fitted, then the carburettor may require recalibration.

8.4 Storage

The storage of the engine is important to both its life and trouble-free operation. Before storage the following procedure should be carried out:

Drain the carburettor by allowing the engine to run at idle speed with the fuel line disconnected, until the engine stops, indicating the carburettor has run dry.

WARNING:

> MAKE SURE IGNITION SWITCH IS IN OFF POSITION AND DISCONNECT SPARK PLUG LEADS BEFORE WORKING ON ENGINE.

Clean the exterior of the engine thoroughly and replace the keeper plate on the ignition flywheel.

Remove spark plugs and pour approximately 5cc of the recommended 2-stroke oil (see general data) into each cylinder and crank the engine by hand a few times to spread the oil throughout the cylinders. Replace the spark plugs leaving the spark plug leads disconnected.

During storage crank the engine by hand each month, with the spark plugs removed.

9. TROUBLE SHOOTING

The essential requirements for easy starting and reliable performance are: - correct fuel, good ignition and good compression.

This trouble-shooting guide will help to determine the cause of trouble. If the trouble persists or seems difficult to repair, contact the engine manufacturer.

WARNING:

MAKE SURE IGNITION SWITCH IS IN OFF POSITION AND SPARK PLUGS LEADS ARE DISCONNECTED BEFORE WORKING ON ANY PART OF THE ENGINE OR ANCILLARY EQUIPMENT.

TROUBLE SHOOTING

	Cause	Remedy
9.1	Difficult starting or will not start	

WARNING:

DO NOT OPERATE ENGINE UNTIL THE CAUSE OF THE TROUBLE HAS BEEN DETERMINED AND RECTIFIED. IF IN ANY DOUBT, CONTACT THE ENGINE MANUFACTURER.

	Cause	Remedy
9.1.1	Lack of Fuel	
9.1.1.1	Fuel tank empty.	Re-fill fuel tank with fresh fuel mixture
9.1.1.2	Fuel line pinched or disconnected	Repair or replace
9.1.1.3	Blocked vent hole filler cap	Clear vent hole
9.1.1.4	Fuel filter blocked	Replace
9.1.1.5	Fuel pump not functioning (if fitted)	Repair or replace

	Cause	Remedy
9.1.2	Poor or no ignition spark	
9.1.2.1	Ignition not turned on	Switch ignition to ON
9.1.2.2	Spark plug wet or carbon fouled	Replace
9.1.2.3	Spark plug electrodes broken	Replace
9.1.2.4	Spark plugs improperly gapped	Reset plug gap (see general data)
9.1.2.5	Wiring harness loose or broken	Repair or replace
9.1.2.6	Module to flywheel incorrectly gapped	Set to correct gap (See general data)
9.1.2.7	Ignition switch faulty	Repair or replace
9.1.2.8	Ignition coils faulty	Replace
9.1.2.9	Ignition module faulty	Replace
9.1.3	Incorrect fuel/air mixture	
9.1.3.1	Engine flooded, over-rich mixture	Fully open throttle and crank engine until it fires. Check carburettor settings
9.1.3.2	Fuel stale, does not vapourise properly	Empty fuel tank and fuel system; refill with fresh fuel
9.1.3.3	Water in fuel	Empty fuel tank and fuel system; refill with fresh fuel
9.1.3.4	Carburettor loose, air leak	Tighten all fastenings
9.1.3.5	Dirt or gum forming in fuel system	Clean system
9.1.4	Poor Compression	
9.1.4.1	Spark plug loose	Tighten to correct torque (See general date)

	Cause	Remedy
9.1.4.2	Cylinder head loose	Tighten cylinder head screw to correct torque (See general data). Replace cylinder head gasket if required.
9.1.4.3	Cylinder head gasket 'blown'	Replace
9.1.4.4	Piston rings broken	Replace
9.1.4.5	Piston and cylinder worn	Replace
9.1.5	Cranks too slow (If electrical start fitted)	
9.1.5.1	Loose or corroded battery connections	Clean battery terminals and refit
9.1.5.2	Weak battery	Charge battery or replace
9.1.5.3	Starter solenoid faulty	Repair or replace
9.1.5.4.	Moisture in starter	Strip and clean, or replace

9.2 Running Troubles

WARNING:

DO NOT OPERATE ENGINE UNTIL THE CAUSE OF THE TROUBLE HAS BEEN DETERMINED AND RECTIFIED. IF IN ANY DOUBT CONTACT ENGINE MANUFACTURER.

	Cause	Remedy
9.2.1	Low Power	
9.2.1.1	Poor quality or incorrectly mixed fuel	Empty fuel tank and refill with fresh fuel
9.2.1.2	Water in fuel	Empty fuel tank and carburettor, refill with fresh fuel
9.2.1.3	Air inlet restricted	Clean or replace
9.2.1.4	Exhaust port or silencer blocked	Clean or replace

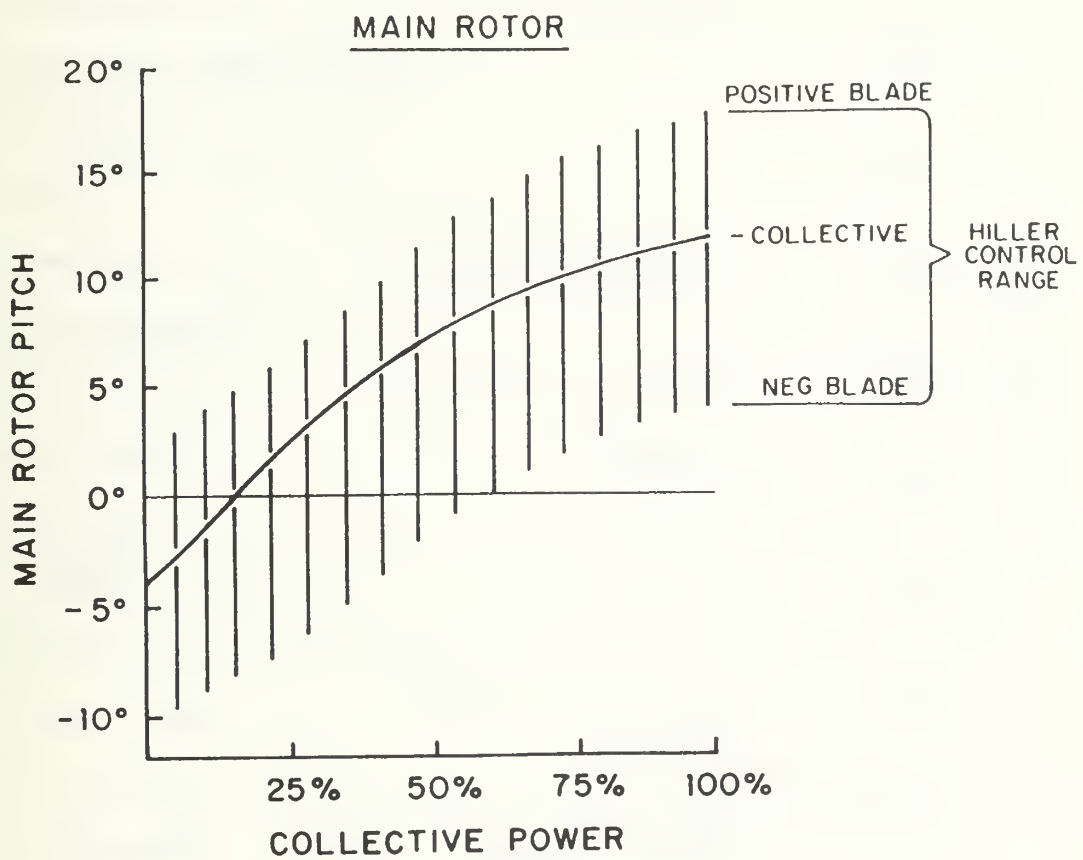
	Cause	Remedy
9.2.1.5	Incorrectly adjusted carburettor	Re-adjust carburettor
9.2.1.6	Poor compression	Repair unit to correct
9.2.1.7	Loose carburettor	Tighten all fastenings
9.2.2	<u>Runs unevenly</u>	
9.2.2.1	Spark plugs in poor condition	Replace
9.2.2.2	Incorrect spark plugs	Replace
9.2.2.3	Wiring harness leads loose	Repair or replace
9.2.2.4	Fuel vapourising in carburettor from overheating	Check installation for source of heat and remedy
9.2.3	<u>Poor acceleration</u>	
9.2.3.1	Blocked or dirty air filter	Clean or replace
9.2.3.2	Carburettor incorrectly adjusted or malfunctioning	Re-adjust carburettor
9.2.3.3	Dirt on carburettor inlet needle	Clean and re-set
9.2.3.4	Exhaust ports heavily blocked with carbon	Clean and re-fit
9.2.3.5	Fuel pump (if fitted) not functioning correctly	Check and clean. Fit new gaskets and diaphragms if required
9.2.4	<u>Will not accelerate</u>	
9.2.4.1	Carburettor incorrectly adjusted or malfunctioning	Re-adjust carburettor
9.2.4.2	Carburettor and/or manifold loose	Tighten all fastenings
9.2.4.3	Fuel pump (if fitted) not functioning correctly	Check and clean. Fit new gaskets and diaphragms if required

	Cause	Remedy
9.2.5	Backfires through carburettor	
9.2.5.1	Damaged reed valve assembly	Repair or replace
9.2.5.2	Air leakage from faulty gaskets seating	Replace gaskets and ensure fastenings are correctly torqued
9.2.6	Detonation under load (Full throttle)	
9.2.6.1	Excessive carbon build up on piston and combustion chamber	De-carbonise engine parts affected
9.2.6.2	Spark plugs incorrect heat range	Replace (see general data)
9.2.6.3	Carburettor fuel, set too lean	Re-adjust carburettor
9.2.7	Engine stops	
9.2.7.1	Fuel tank empty	Refill fuel tank with fresh fuel
9.2.7.2	Fuel vapour locks in fuel system	Clear system of vapour, check installation for source of heat and correct
9.2.7.3	Ignition turned off	Switch ignition on
9.2.7.4	Exhaust blocked	Clean or replace
9.2.7.5	Clogged or restricted air cooling system; cooling fan (if fitted) damaged	Ensure air cooling system is clear of any blockage or debris
9.2.7.6	Incorrect fuel/oil mixture	Empty fuel tank and refill with fresh fuel
9.2.7.7	Fuel line between tank and carburettor blocked	Clean or replace
9.2.7.8	Carburettor air inlet filter blocked	Clean and replace

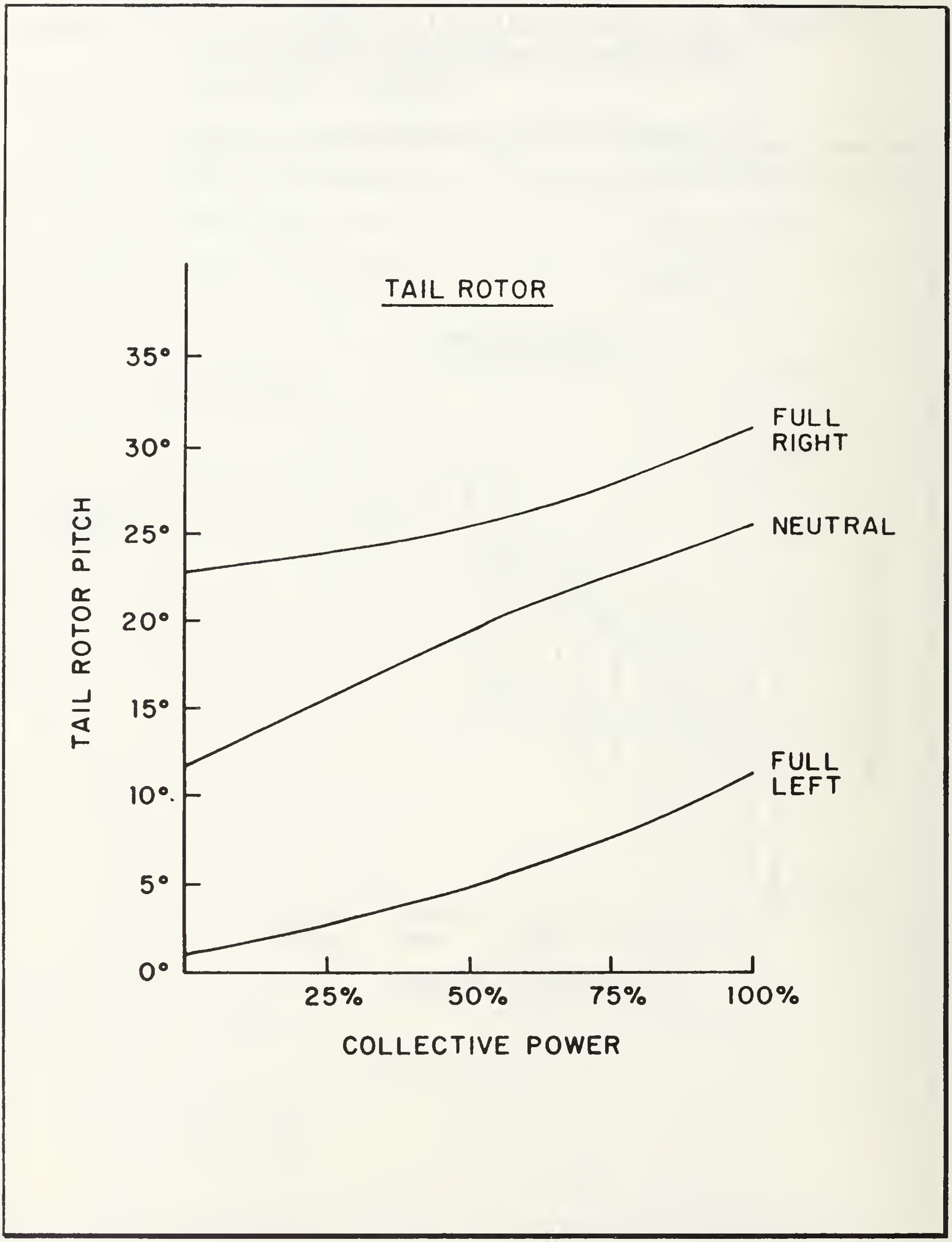
	Cause	Remedy
9.2.7.9	Carbon fouled spark plugs	Replace
9.2.8	<u>Carburettor floodings</u>	
9.2.8.1	Fuel pump (if fitted) excessive pressure	Reduce pump pressure, clean system
9.2.8.2	Dirt in inlet valve	Flush to clean
9.2.8.3	Inlet valve defective	Replace

APPENDIX D: MAIN AND TAIL ROTOR RIGGING DATA AND AIRCRAFT CHARACTERISTICS

MAIN ROTOR COLLECTIVE POWER vs PITCH



TAIL ROTOR COLLECTIVE POWER vs PITCH



HUMMINGBIRD 1 CHARACTERISTICS

Main and tail rotor rigging data

Main Rotor Blade Pitch

Low	0.0-0.5°
Hover	7.0°
High	10.0-11.0°

TRB Pitch

Compensation on	15.0-18.0°

Bell-Hiller Paddle Angles

Roll	± 7.0°
Pitch	± 11.0°

Aircraft Characteristics

Characteristics

Empty Weight	142 pounds
Fuel Weight	7 pounds
Gross Weight	149 pounds
Length	12 ft 3 inches
Fuselage Length	9 ft 11 innches
Fuselage Width	1 ft 3 inches
Tread Width	2 ft 6 inches
Height	3 ft
Static Tipover Angle	40°

Rotor Parameters

Main Rotor Radius (R)	5 ft 0.25 inches
Bell-Hiller Radius	4 ft 2 inches
Main Rotor Chord (C)	6.125 inches

Main Rotor Blade Length	4 ft 6.25 inches
Main Rotor Thickness	0.6875 inches
Solidity Ratio	0.065
Tail Rotor Radius	11.5 inches
Tail Rotor Chord	2.75 inches
Tail Rotor Thickness	0.3125 inches
<u>Engine and Gearing</u>	
Engine	Westlake 342 Series 2100D
Maximum Power	25 BHP @ 7000 RPM
Maximum Torque	25 ft-lb @ 4000 RPM
Engine/Main Rotor Gear Reduction	10 : 1
Tail Rotor/ Main Rotor RPM Ratio	4 : 1

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